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LONG-TERM APPLIED RESEARCH IN CONSTRUCTION MATERIALS OF MINERAL ORIGIN IN CANADA WITH PARTICULAR REFERENCE TO CANMET

by

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EXECUTIVE SUMMARY

This report, commissioned by CANMET, gives an overview of long-term *applied* research in the areas of aggregate, cement and concrete in Federal government agencies, Provincial government agencies, universities and industry in Canada and considers this research in relation to work done at CANMET. It is concluded that work done at CANMET does not overlap with work elsewhere. CANMET's research projects appear to be well geared to the needs of the country and the mechanism of transfer of technology of research done at CANMET is judged to be satisfactory by a wide range of people in industry and in agencies active in research. However, some minor improvements are suggested.

The report reviews a number of possible areas of future research and technological study particularly relevant to climatic and geographical conditions of Canada and advantageous from the standpoint of resource conservation and energy savings. These seem to be: durability of concrete in cold inland water and in sea water; durability of concrete in bridges and parking garages; use of marginal aggregates; use of waste materials as aggregate, including

development of economic production of lightweight aggregate; use of *Canadian* fly ash; and use of blastfurnace slag and of additives to cement in general in order to reduce the consumption of cement.

A comparison of long-term applied research in Canada with that in other industrialized countries indicates that the Canadian effort is relatively low. For instance, compared with France and the United Kingdom, the Canadian expenditure per value of cement produced is, at best, about one-half, and on the basis of GNP, one-third or less of that in the other two countries. The Canadian industrial expenditure seems especially low. Data on long-term applied research in the U.S. are not available so that a comparison with Canada, which would clearly be interesting, cannot be made.

Bearing in mind the very high value of building materials, it is noted that a judicious choice and use of these materials can result in considerable energy and resource savings. Since aggregates and waste materials vary enormously, a study of their *actual* properties is necessary, and therefore reliance on research done elsewhere is not possible. The same applies to many durability problems.

Since the issues are those of materials of mineral origin and of energy, CANMET seems an appropriate agency to undertake the necessary long-term applied research. In the United States and in the United Kingdom, corresponding government departments are involved in projects dealing with aggregate, cement and concrete.

CANMET also appears to be the only centre of concentrated expertise in Canada, and such a "centre of excellence" is essential for improvements and especially for energy economies in the use of aggregate, cement and concrete. Expansion of CANMET's in-house work seems therefore to be highly desirable.

In order to encourage development of local facilities, it is also desirable for CANMET to expand its contracting-out activities. However, with time, industry should be expected to support work in the various laboratories direct.

Since, government research should be done for a customer, it is averred that the customers are:

a) Federal and Provincial governments, because the public sector is a large purchaser of concrete and it is therefore in the public interest to influence the relevant industry and to encourage it to develop its own R & D activities; b) the aggregate industry because it is unable to do its own research and it is in the national interest to optimize the use of this mineral resource; and c) the concrete and construction industries, because they are not based on product competition and perceive no benefit for themselves in research whose results are available for all to use.

In summary, CANMET's work is seen to be highly valuable and applicable, and its expansion is recommended.

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CHAPTER 1

MISSION OF THE STUDY

This study was requested by the Minister of the Department of Energy, Mines and Resources with the following mission.

1. To identify government, industrial and educational institutions engaged in long-term applied research (distinct from curiosity oriented research) in the areas of construction materials of mineral origin, aggregates, cement and concrete, in Canada and to summarize their level of efforts in terms of man-years and dollar value.

2. To compare the current projects in Construction materials of mineral origin, Minerals Research Program, CANMET, with similar programs in (1) above to determine the degree of overlap if any. Further to determine if sufficient liaison exists between various federal groups engaged in research in construction materials of mineral origin to minimize overlap and duplication.

3. To evaluate the relevance and effectiveness of current projects in construction materials of mineral

origin, Minerals Research Program, CANMET, in terms of the needs of the country and to determine if there is a satisfactory mechanism of transfer of technology of the research being done at CANMET.

4. To determine if sufficient R&D work is being contracted out to meet CANMET's objectives in terms of "make and buy" policy.

5. To identify areas of needed research in construction materials of mineral origin in Canada, taking into account the climatic and geographical conditions of the country.

6. To identify technological opportunities for research in construction materials of mineral origin in the areas of resource conservation and energy savings.

7. To compare in a general manner the Canadian effort in applied research in the areas of construction materials of mineral origin with that of other industrialized countries.

To carry out this task I visited a large number of institutions right across Canada; a list of the people interviewed and of those who wrote to me is given in Appendix A. They were all very helpful and

I am most grateful to them for their time and their courtesy.

The results of the interviews are reported in Chapters 3 to 9. Because Item 1 of the Remit contains the greatest amount of information, it is covered in four chapters (3 to 6), each concerned with a different type of institution: Federal agencies; Provincial agencies and Crown corporations; universities; industrial laboratories. The chapters are summaries of the information obtained, detailed information about individual institutions being given in appendices.

Item 2 is dealt with in Chapter 7. Chapter 8 discusses Items 3 and 4, and Chapter 9 Items 5 and 6. Finally, Item 7 is dealt with in Chapter 10.

Chapter 2 serves as an introduction and describes the Federal Government policy on research and gives a very brief review of the cement, aggregate, and concrete industries. Conclusions of the study are reported in Chapter 11.

CHAPTER 2

BACKGROUND TO GOVERNMENT AND OTHER RESEARCH ON CEMENT, AGGREGATE AND CONCRETE IN CANADA

Part 1

A review of the long-term applied research on cement, aggregate and concrete done by CANMET both in-house and contracted out and a comparison with research done elsewhere should be made against the background of Federal government policy.

This policy with respect to contracting out the requirements in science and technology was laid down by the Treasury Board in 1977. The background to it is as follows. "As part of its strategy for obtaining a more even balance between the in-house and industrial performance of its scientific requirements, the government has provided, since 1972, that its new requirements for mission-oriented research, development and feasibility studies in the natural sciences are to be contracted-out to industry, unless specifically otherwise provided. In 1974, this policy was extended to permit the government to respond promptly to sound, unique, unsolicited proposals from the private sector

in support of government science missions. As part of these arrangements, a special fund was established in the Department of Supply and Services to finance such unsolicited proposals until funds can be allocated to the project through the normal budgetary process."

The guidelines state: "As a general principle, the government's mission-oriented, Science and Technology requirements are to be contracted-out to the private sector for performance inside Canada. However, where a department considers it to be inappropriate to contract-out to the private sector, the onus is on the dpeartment, with due regard for the optimum benefit to Canada, to justify why an alternative performer is preferable (i.e. why the requirement should be performed in-house or outside Canada)."

In the above, "Mission-oriented science and technology requirements of government are those requirements for the performance of scientific activities in the natural sciences and in the human science fields of urban, regional and transportation studies that support departmental missions. In some cases the departmental mission may itself be scientific (e.g. to improve the geological description of Canadian land masses); more often the mission is not specifically scientific, but has the potential for partial or

complete fulfillment through a scientific activity (e.g. to promote the more effective use of land)."

Since the present report is concerned solely with long-term applied research, it is useful to quote the following Treasury Board definitions.

"Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. It analyzes properties, structures and relationships with a view to formulating and testing hypotheses, theories or laws and is usually undertaken by scientists who may set their own goals and to a large extent organize their own work. However, in some instances basic research may be primarily oriented or directed towards some broad fields of general interest. Such research is sometimes called "oriented basic research"."

"Applied research is also original investigation undertaken in order to acquire new knowledge, but directed primarily towards a specific practical objective. It may be undertaken to determine either possible uses for the findings of basic research or new ways of achieving specific and pre-determined objectives. It involves the consideration of the

available knowledge and its extension in order to solve particular problems. In Business Enterprise the distinction between basic and applied research is often marked by the creation of a new project to explore any promising results of a basic research program. The results of applied research are intended primarily for a single or limited number of products, operations, methods and systems. The knowledge or information derived is often patented, but may also be kept secret."

Following these generalities on the Federal government research policy, it may be appropriate to quote from "Mineral Policy Objectives for Canada - a statement by federal and provincial ministers responsible for mineral policy." This says: "Minerals are a fundamental component of the nation's material and economic base . . . The opportunity to obtain significant net benefits from our mineral heritage is a complex but rewarding challenge." And further "One of the objectives of the "mineral policy" is to encourage the highest possible efficiency and returns associated with all technological research and development in Canada." Another is to "undertake and encourage research aimed at developing more efficient methods of winning materials from minerals." Also, to

"facilitate the substitution of abundant for scarce mineral materials" and to "increase the recovery and recycling of scrap and waste materials."

Let us now turn to the Canada Centre for Mineral and Energy Technology (CANMET) of the Department of Energy, Mines and Resources. As its Director-General said in 1976, CANMET has played a prominent role in Canada for over 50 years in the research and development of cementitious materials of mineral origin. In recent years, the department has become involved increasingly in research on these materials in order to conserve both resources and energy.

The prime functions of CANMET are clearly described in the Introduction to the CANMET Review 1978-79: "assuring effective utilisation of minerals and energy, developing new technology, and assuring the availability of energy from innovative as well as traditional sources."

The specific research topics investigated at CANMET are described in Chapter III and in Appendix B. These all fall into the long-term applied research category, which of course is the scope of this report. Some of the CANMET research is contracted out but to assess the possible extent to which research can be

contracted out can be judged only in relation to the facilities in industry and elsewhere.

Part 2

Before research at CANMET can be evaluated, let alone compared with research work done elsewhere, it is useful to review briefly the cement, aggregate and concrete industries in Canada.

Concrete industry in Canada has been in existence for a century, the first Portland cement plant being established in Hull, Québec in 1889.

At present, there are 24 cement plants with 51 kilns in Canada, located in all provinces except Prince Edward Island. The production of cement in 1978 was 10.5 million tonnes valued at $572 million. In the 1970s many technological advances were made by the Canadian cement industry and new equipment was installed. Continuing export of cement to the U.S. was advantageous.

It may be worth noting the degree of foreign ownership of the Canadian cement and concrete industry: more than one-half of Canada Cement Lafarge and of Genstar and almost one-half of St. Lawrence Cement are foreign-owned.

Aggregate is produced by about 300 firms ranging from 20,000 to 4 million tonnes per year. All districts are served by local pits and quarries with delivery distance rarely in excess of 50 km. In 1974, the total consumption of sand and gravel, stone and cement in Canada was about 340 million tonnes, or 15 tonnes per head. This figure prompted G. W. Riley* to comment that we are still in the middle of the Stone Age.

There is little lightweight aggregate manufactured in Canada; in recent years, some plants have closed down but others have been opened. In 1979, there were eight plants in operation with the production of expanded clay, shale and slag totalling 521,000 m^3 and a value of $8.5 million.

It is relevant to note that ready-mix concrete suppliers are generally small firms: 40 to 60 trucks in metropolitan areas and possibly only six in rural districts. According to the report of the Sector Task Force on the Canadian Cement and Concrete Industry, the numbers of employees in 1975 were distributed as follows:

Number of employees	Number of plants
1-9	120
10-19	102
20-49	90
50 or more	44

* Manager, Mineral Processing Laboratory, Mineral Sciences Laboratories, CANMET.

Many block plants are also small and sell in a local market. Precast concrete plants producing structural elements are larger and typically have 50 to 100 employees but some are larger still and ship their products over a distance of several hundred kilometres.

There is one special feature of the Canadian cement, aggregate and concrete industry: the so-called vertical integration. The following description has been given in a report by the Sector Task Force on the Canadian Cement and Concrete Industry.

"Vertical integration is a significant feature of the cement and concrete industry. The five largest cement companies own or control an undisclosed number of ready-mix, concrete and aggregate business establishments, estimated at 30 per cent of the total number of establishments with perhaps 60 per cent of the value of output. This integration is concentrated in the metropolitan areas and the larger business establishments. Independent producers of ready-mix and concrete products are typically smaller producers in the large cities, or medium to small producers in smaller centres. In contrast, a number of large producers of aggregate are not integrated with other businesses."

"Vertical integration in the sector began about 1958 with the cement companies buying out their largest customers, ready-mix companies, to protect their shares of the cement market. Since ready-mix concrete consumes about 70 per cent of Canada's Portland cement, there has been a large incentive for this integration step. The concrete products industry is a smaller consumer of cement and consequently there has been less vertical integration there. Other acquisitions or expansions have been in the trucking business and in aggregate production to control major cost elements. For example, from the standpoint of ready-mix or concrete products manufacturers, the cost of aggregate ranges from 11 to 22 per cent of the total cost of materials. In a more extreme example, the cost of transporting aggregate by truck may range from 30 to 100 per cent of the sum of other costs."

"In the case of aggregate, while some producers are affiliated with the cement and concrete sector, an important number of companies are primarily concerned with aggregate for other purposes such as road-building, bases for building foundations and railroad ballast. Concrete accounts for only about *20 per cent* of the aggregate supplied for all construction purposes. Aggregate and concrete production are therefore connected to an important extent, but there are many producers of aggregate to whom demand from the concrete industry is incidental."

To put the size of the industries discussed in a proper perspective we can note that in 1976 the value of the metallic and non-metallic mineral industry was about $16.2 billion, of which the cement, aggregate, and concrete components accounted for about $1.8 billion or 11 per cent of the total production value of the metallic and non-metallic mineral industry.* The number of people employed in the industry was about 23,000 or 12 per cent of the total of about 197,000 who were employed in 1976 by the metallic and non-metallic mineral industry.

Since the cement, aggregate and concrete industry is a supply industry to the construction industry, the cement, aggregate and concrete activity is very largely dependent on the overall construction activity. While this is also true of structural steel, the steel industry, unlike the cement industry, has many non-construction outlets.

Data on cement-use, according to the type of construction in Canada, are not readily available but U.S. data for 1976, reported by the U.S. National Materials Advisory Board report, published in 1980 may be of interest. The percentage of cement use according to the type of construction is as follows:

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* Data from G. W. Riley, Manager, Mineral Processing Laboratory, Mineral Sciences Laboratories, CANMET.

residential	31
industrial and commercial	24
public buildings	7
other construction	17
highways	16
miscellaneous	5.

Some statistical data for Canada are given in Tables 2a-2d.

From the above, we can see the cement, aggregate and concrete industry in Canada as adequate to satisfy Canada's needs and also able to export cement. The concrete industry is fragmented by the type of activity, and, in addition, within practically every type, there is a large number of small firms, as well, of course, as some large ones, but no very large ones. This fragmentation is modified by vertical integration. The degree of foreign ownership should also be noted. All these factors influence the industry's attitude to research.

Table 2a: Annual value of construction between 1971 and 1980*

Year	New works	Repair	Total construction	Per cent variation in current dollars	Total construction as percentage of Gross National Expenditure	
	Millions of current dollars				in current dollars	in constant 1971 dollars
1971	13,276	2,589	15,865	15.1	16.8	16.8
1972	14,469	2,820	17,289	9.0	16.4	16.3
1973	16,954	3,220	20,174	16.7	16.3	16.0
1974	20,772	3,921	24,693	22.4	16.7	16.0
1975	24,056	4,320	28,376	14.9	17.2	16.2
1976	28,145	4,986	33,131	16.8	17.3	16.2
1977	30,130	5,673	35,803	8.1	17.1	15.8
1978	31,910	6,280	38,190	6.7	16.6	15.2
1979	35,471	6,900	42,371	10.9	16.3	15.0
1980	38,796	7,622	46,418	9.6		

* from Statistics Canada 64-201

Table 2b: Value of various types of construction in 1977*

Type of construction	Value $ millions	Per cent of total
Building		
Residential	13,126	36.7
Industrial	1,729	4.8
Commercial	3,639	10.2
Institutional	1,662	4.5
Other building	1,152	3.2
Total building construction	21,308	59.5
Civil Engineering		
Marine	242	0.7
Highways and airport runways	2,691	7.5
Waterworks and sewerage	1,669	4.6
Dams and irrigation	154	0.4
Electric power	3,401	9.5
Railways and telephones	1,356	3.8
Gas and oil facilities	2,724	7.6
Other engineering construction	2,259	6.3
Total engineering construction	14,497	40.5
TOTAL	35,804	100.0

* from Stonehouse, *Cement*, 1979

Table 2c: Production of cement in Canada*

Province	Number of plants	Production of cement in 1978	
		tonnes thousands	value $ thousands
Newfoundland	1		5,685
Nova Scotia	1		12,128
New Brunswick	1		12,643
Québec	5	2,809	130,147
Ontario	7	3,953	183,110
Manitoba	2	681	34,544
Saskatchewan	1	353	24,689
Alberta	2	1,167	113,537
British Columbia	4	1,019	56,107
Canada total	24	10,558	572,590
Type of cement			
Portland		10,191	
Masonry ‡		367	

‡ includes small amounts of other cements
* after Stonehouse, *Cement*, 1979

Table 2d: Size of the concrete industry in 1978*

Segment of industry	Number of establishments	Number of employees	Value of production $ millions
Cement	29	2,873	526
Concrete products (block, brick, pipe, tanks, poles)	499	8,265	533
Ready-mix concrete	440	7,471	762

* after Statistics Canada 44-204, 44-205 and 44-211

CHAPTER 3

LONG-TERM APPLIED RESEARCH IN FEDERAL AND GOVERNMENT AGENCIES

The Federal Government contributes to long-term applied research on cement, aggregate and concrete directly only through two bodies: the National Research Council and CANMET. Each of these agencies does in-house research and also gives support for research to be done elsewhere; in the case of the National Research Council this is through the grants of NSERC and in the case of CANMET a small number of outside contracts is arranged.

One other Federal agency should be mentioned: PFRA (Prairie Farm Rehabilitation Administration). The work of this organization in the field considered is very limited and mainly of interest to the Prairie Provinces.

A list of people interviewed at NRC, at PFRA and at CANMET is given in Appendix A. An account of the research described at these interviews is presented in Appendix B; Table 3a summarizes this information together with the effort expended in dollars and man-hours per annum by each agency.

Table 3a: Long-term applied research by Federal agencies

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
National Research Council	New test methods for alkali-reactive aggregates	Mechanism of reactivity and basic properties of fly ash: accelerators or catalysts for hydraulic reaction of fly ash Mica-reinforced cement studies Basic work on admixtures Basic mechanism of frost action and use of incorporated fine materials in lieu of entrained air *continued . . .*	Investigation of frost damage in parking buildings	*see continuation*	

Table 3a (*continued*): Long-term applied research by Federal agencies

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
National Research Council *continued*		Study of corrosion from physical-chemical standpoint and accelerated assessment of durability		Total for all projects 3.5	120,000
Canada Centre for Mineral and Energy Technology (CANMET)	Use of marginal aggregates and of waste materials as aggregate Lightweight aggregate of economic value in Canada	Energy conservation in construction industry, including use of fly ash, slag, silica dust and superplasticizers CSA comparative cement: sample program	Behaviour of Portland and high-alumina cement at ambiant and elevated temperatures Long-term performance of concrete in marine environment		
		continued . . .	*continued . . .*	*see continuation*	

Table 3a (*continued*): Long-term applied research by Federal agencies

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Canada Centre for Mineral and Energy Technology (CANMET) *continued*		Performance of Canadian fly ash	Performance of concrete in acidic waters of Northern Canada In-situ strength determination Effect of low temperatures on concrete, especially in relation to the length of the freezing cycle	Total for all projects 9.0	450,000 +75,000 for contracts

Table 3a (*continued*): Long-term applied research by Federal agencies

Agency				Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Prairie Farm Rehabilitation Administration		Use of fly ash in concrete under sulphate attack made with Types I and V cement (20 year project)		0.2	6,000
TOTALS 4	3	9	10	12.7	651,000

CHAPTER 4

LONG-TERM APPLIED RESEARCH IN PROVINCIAL AGENCIES AND CROWN CORPORATIONS

The work of the Provincial Agencies and Crown Corporations is, not surprisingly, uneven with regard to research topics. Naturally, such bodies as the Ministries and Departments of Transportation and the Hydro-electric authorities are very much occupied with investigations of concrete. Cement is not studied, apart from work done on the utilization of fly ash in conjunction with Portland cement, and aggregate, too, receives little attention.

The effort expended in both man-years and dollars seems low considering the quantity of concrete used by the Provincial agencies. However, some of their research work is contracted out to industry or to universities and this is reported under those headings (including the man and dollar effort). Moreover, most of the investigations are in the nature of immediate problem-solving, either before or during construction and, subsequently, due to deterioration of their structures in-use.

A summary of the investigations undertaken by the Provincial Agencies and Crown Corporations is given

in Table 4a. Appendix A gives a list of the people interviewed or contacted at these places and Appendix C gives a descriptive account of the work being done there.

Table 4a: Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
British Columbia Hydro and Power Authority	Investigation of aggregate sources	Use of admixtures and fly ash	Creep, thermal properties, strain capacity	3.0	200,000 much contracted out
	All work concerned with field problems				
Manitoba Hydro			Study of long-term performance of concrete in existing structures: air-void analyses, compressive strength tests, and accelerated freeze-thaw tests	not manpower or cost intensive	

Table 4a (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Ontario Hydro	Alkali-aggregate reaction	Utilisation of fly ash (Some CANMET Contracts) Use of cement grout in stabilization of waste and of fly ash slurry for back-fill (AECL Contracts) Temperature rise in cables with differing types of backfill Superplasticizers (CANMET Contract)	Temperature cycling of mass concrete Creep of fly ash concrete	Total for all projects (total 9.0) estimated long-term research component 6.0	(total 500,000) 300,000

Table 4a (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Hydro-Québec	All work contracted out; no research laboratories				
Nova Scotia Power Corporation	Alkali-reactive aggregates (see N.S. Technical University, Table 5a)			Work contracted out	
British Columbia Ministry of Transportation and Highways	Standardized format developed to describe aggregate Various tests applied to determine aggregate quality and achieve normalization of tests *continued . . .*		Use of high-alumina cement concrete for bridge deck overlay and other purposes Other specific studies e.g. durability and wear resistance of bridge decks, and cracking of bridge decks		*see continuation*

Table 4a (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
British Columbia Ministry of Transportation and Highways *continued*	Other specific studies, e.g. role in frost heave			Total for all projects 1.0 (estimate)	30,000 (estimate)
Ontario Ministry of Transportation and Communications	*continued . . .*	*continued . . .*	Deterioration of bridge decks Durability of concrete structures Electrical impedance of concrete Variation of strength in concrete columns		

Table 4a (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Ontario Ministry of Transportation and Communications *continued*		Properties of various cements Use of blastfurnace slag		Total for all projects	
	Influence of aggregate on cracking			8.0	250,000
Ministère des Transports (Québec)			Deterioration of concrete: study of correlation between behaviour of concrete in structures and laboratory tests on aggregate	1.0	30,000
	Alkali-aggregate reaction			1.0	37,000

Table 4a (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
New Brunswick Department of Transportation	A fixed concrete laboratory and mobile laboratories for testing				
Centre de Recherche Industrielle de Québec			Development of polymer concrete for use in external wall panels Development of light-weight polymer concrete	2.0	65,000
	Manufacture of expanded clay and shale aggregate in suspension kiln		Efflorescence on concrete block	1.0	35,000

Table 4a (*continued*): Long-term applied research in Provincial agencies and Crown corporations

Agency	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Research and Productivity Council, New Brunswick		Utilization of local fly ash (proposed)			(Proposed expend-iture: 10,000 to 20,000)
TOTALS 11	8	7	17	23.0	947,000

CHAPTER 5

LONG-TERM APPLIED RESEARCH IN UNIVERSITIES

As far as universities in Canada are concerned, I have to admit that I have not been able to visit all of them, but I limited myself to those where, from my personal knowledge and from enquiries, some research on concrete is being pursued. These universities are not numerous and the amount of long-term applied research falling within the scope of this report is small, and probably smaller than, say, ten or fifteen years earlier.

The universities visited and the faculty members interviewed or contacted are listed in Appendix A. A descriptive presentation of the research undertaken is given in Appendix D. Table 5a presents a summary of the findings: this includes the level of effort in man-years and dollars per annum. The activity in the universities which I have not visited is probably so small as not to alter the figures quoted by more than a few per cent.

At the thirteen universities listed, the bulk

of the investigations were, quite properly, in the field of concrete. Aggregate and cement were relatively little studied and it should be noted that, for the purposes of this table, most of the studies on blastfurnace slag, fly ash, and superplasticizers, were categorized under cement.

More than half a million dollars were spent on this research and 28 man-years of effort expended. However, we should remember that universities do not normally have to take into account cost of overheads and equipment at their institutions. No doubt some 'hidden man-years' of technicians' and secretaries' work are also sometimes overlooked. It should also be noted that some contract money may be listed under the university, as well as under the granting body (e.g. Provincial agencies).

One other factor is worth noting. Universities depend on the availability of both their own money, and money from agencies giving them contracts, to carry out research. They also depend on a supply of postgraduate students to carry out this work. Since the supply of both money and students fluctuates, so does their work which may thus vary more rapidly in quantity and type than industrial or government research.

Table 5a: Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of British Columbia (Mindess)	Aggregate-paste bond to establish permeability at interface under high water pressure (initial stages still)	Cement-wood fibre composites Crack propagation in cement and mortar under stress	Development of large impact machine to test steel fibre concrete	Total for all projects 1.4	50,000
University of Alberta	-	-	-	-	-
University of Calgary (Ward)			Freeze-thaw properties of mass concrete	4.0	100,000
			Durability of spun poles, bridge piers, railway ties	0.1	2,000
			Properties of masonry walls	0.5	20,000

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of Calgary (Joshi)		Cementitious properties of fly ash		1.5	20,000
			Low-strength concrete using fly ash, lime, Portland cement	1.0	25,000
University of Calgary (Johnston)	Use of fly ash to reduce alkali-aggregate reaction		Freeze-thaw properties of fly ash concrete with air-entrainment	2.0	18,000
			Superplasticizers and waste materials for high strength concrete (CANMET contract)	1.0	24,000

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of Saskatchewan (Nasser)		Saskatchewan fly ash as partial replacement for Portland cement		2.0	16,000
		Strength and bond of masonry cement		1.0	5,000
			New techniques and methods for control of concrete	1.0	25,000
University of Windsor (MacInnis)	Specifications for aggregate			Total for all projects	
	Aggregate beneficiation		Creep, shrinkage and durability	3.0	100,000

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
McMaster University	*see* p.50 (Table 6a) and pp. 146-147				
University of Toronto (Mills)		Part substitution of blastfurnace slag and fly ash for Portland cement		0.2	4,000
University of Toronto (Timusk)			Glass-fibre reinforced polymer-modified materials (non load-bearing) Dampness and temperature stresses in foundations of small buildings	Total for all projects 0.2	10,000

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Queen's University (Hope)	Mix design using aggregates of poor grading	Autoclaving with fly ash (CANMET contract)	Vacuum processing of concrete ISO test method for permeability (CANMET contract) Electrical conductivity (steel corrosion study)	Total for all projects 1.0	30,000
McGill University	-	-	-	-	-

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Université de Montréal Ecole Polytechnique (Houde)	Durability of local aggregate containing shale		Prediction of strength after early freezing and different types of curing	1.5 0.5	10,000 2,500
Université de Sherbrooke (Aïtcin)		Study of superplasticizers	Study of high strength concrete (>100 MPa) Light-weight concrete with bubble aggregates Use of industrial by-products in concrete	Total for all projects 2.8	60,000

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Université Laval (Pigeon)			Durability when subjected to long cycles of freezing and thawing Properties of cold concrete	Total for all projects 1.2	10,500
University of New Brunswick (Bremner)	Alkali-aggregate reaction of local aggregates (with Department of Geology)		History of structures with deterioration due to alkali-aggregate reaction Strength and deformation of light-weight aggregate concrete, especially under load	Total for all projects 1.1	17,000

continued . . . .

Table 5a (*continued*): Long-term applied research in universities

Institution and research worker reporting	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
University of New Brunswick (Bremner) *continued*		Use of fly ash and blastfurnace slag (CANMET contract)		1.0	25,000
Nova Scotia Technical University (Potyondy)	Alkali-aggregate reactivity of specific local aggregates (completed)			0.1	3,000
TOTALS 13	8	10	22	28.1	577,000

CHAPTER 6

LONG-TERM APPLIED RESEARCH IN INDUSTRY

In describing the research done by industry, we should realize that most of this is research done for clients. Some of these are Provincial or Federal bodies such as CANMET; others are private firms. However, some companies do carry out research on their own product and its development. This is particularly true of Cement Lafarge (a foreign-owned company) who are studying cement production in general and in relation to energy consumption. St. Lawrence Cement and Inland Cement have no research laboratories, but do some work on the use of waste materials in cement production and in concrete.

All Canadian cement manufacturers pay dues to PCA at Skokie, Illinois. Work there is, however, not concerned with specifically Canadian problems.

Industry is giving little attention to research into the use of blastfurnace slag. Here again, the general lack of interest in this topic is surprising, given that about 100,000 tons of slag may be ground at any one plant per annum. Only about 10 per cent of slag will normally be used, even though it may be of good quality.

There is some interest shown by industry in the use of admixtures and superplasticizers. Fly ash, too, receives some attention. Here again, as with slag, there is a problem of excess of the material. British Columbia actually imports fly ash from Seattle, and much British Columbia concrete contains fly ash. In about ten years' time, there will be ample British Columbia fly ash from the new Hat Creek Plant. Already, in Canada, 3,000,000 tons is produced per annum. Only about 100,000 tons of this is used, one-third of it in Ontario (where useable material is in short supply) and the Prairie Provinces. Although fly ash is produced in the Maritimes, it is not used there. Part of the difficulty in utilisation occurs because the period of production of the greatest quantity and best quality of fly ash at the power plants (the winter) coincides with the period of minimum activity in the construction industry and the material cannot be stock-piled easily. Moreover, transport over long distances is uneconomical. Fly ash from some plants cannot be used because of fluctuating carbon content. The problem of air-entrainment in fly ash concrete has not been resolved.

The research topic of no interest to industry is aggregate. Even the ready mix industry has only control laboratories but no research facilities.

The commonly heard gloomy comments on the dwindling supplies of satisfactory and accessible aggregate do not yet seem to be taken seriously in the building industry. It is not yet worth while, apparently, investing money in the study of marginal or unorthodox aggregates.

As in the three preceding chapters, Appendix A lists those people in industry interviewed or contacted and Appendix E describes their research projects. The summary of effort and the type of topic studied in long-term applied research by industry are given in Table 6a below.

Table 6a: Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Canada Cement Lafarge Ltd		Using mineralizers in kiln burning Study of size of clinker. Improving efficiency of clinker mill Flowability of cement powder Study of energy use in manufacture of cement		Total for all projects 2.0	200,000
Canadian Portland Cement Association: Ottawa	All long-term research carried out by PCA in the United States			-	-
Vancouver Halifax	No projects specifically directed to materials in or for Canada			-	-

Table 6a (*continued*: Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Canfarge Ltée		Use of super-plasticizers in air-entrained concrete to obtain high strength Study of mechanism of action of super-plasticizers Retarded mortar	Manufacture of load-bearing concrete with high insulation value - use of polystyrene Improvement of durability by surface coating of concrete moulds	Total for all projects 4.5	500,000 (includes new equip-ment)
Centre of Research and Development in Masonry			New concrete block of sandwich type Work on concrete generally	0.3 1.0	12,000 100,000 (includes new equip-ment)

Table 6a (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Hardy Associates (1978) Ltd		Properties of fly ash with low carbon and high calcium carbonate content		1.0	60,000
		Use of plasticizers: effect of air-void system on durability		1.0	35,000
			Design of mixes Testing of steel fibre reinforced shotcrete	0.3	30,000
Laboratoire de Béton Limité			Durability of concrete in pure and acidic water (CANMET contract - and others)	0.1	7,000
			In-situ strength testing of concrete	0.2	12,000

Table 6a (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Klohn Leonoff			Accelerated testing of shotcrete and grout	0.3	24,000
			Density of fresh and hardened concrete by X-ray emission to determine durability of surface layer	1.0	50,000
B.H. Levelton and Associates Ltd		Work on fly ash and superplasticizers (CANMET contract)	Accelerated curing (CANMET contract)	1.0	30,000
		Admixture systems, grout, hardeners		1.0	35,000
			Specific projects e.g. shotcrete, ultra lightweight concrete, offshore construction, high-strength concrete	2.0	85,000

Table 6a (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
National Boring and Sounding Inc	(Routine Inspection)			-	-
Standard Slag Cement Co			Sulphate resistance of slag concrete (contract to McMaster University)		1,000
		Use of slag cement for lean concrete		0.4	15,000
Sternson Ltd		Work on ligno-sulphonate admixtures to obtain flowing concrete of not very high strength *continued . . .*		*see continuation*	

Table 6a (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Sternson Ltd *continued*		Lime and calcium sulphoaluminate based expansion additives Fibre-reinforced expansive mortar		Total for all projects 2.0	70,000
Trow Ltd			Deterioration of horizontal structures (supported by NSERC and Central Housing and Mortgage Corporation)	1.0	30,000

Table 6a (*continued*): Long-term applied research in industry

Firm	Research topic			Level of effort per annum	
	Aggregate	Cement	Concrete	Man-years	Dollars
Warnock Hersey Professional Services	(Investigations of failures of concrete and structures. Testing for Hydro-Québec)			-	-
TOTALS 13	0	13	12+	19.1	1,296,000

CHAPTER 7

OVERLAP AND DUPLICATION IN RESEARCH

This chapter is concerned with any *overlap* between work done at CANMET and elsewhere and *liaison* between various Federal groups. While, very likely, there is some overlap in many areas of Federal and Provincial research activity, this is not the case with cement and concrete because so little work is done anywhere.

During interviews, the question was asked whether there seemed to be any overlap in the work of the various Federal groups. In not one instance was an example of overlap quoted. Without exception, it was agreed (when the interviewee was familiar with the work of CANMET as well as other Federal agencies, which was by no means always the case) that the work undertaken was "different" or "very different", even if the "title" used by CANMET and another Federal agency like NRC, was the same. Some of the work, it was said, was complementary since NRC, for instance, does not do "concrete work". It was thought that NRC's more basic physics- and chemistry-oriented approach to materials therefore complemented the engineering approach to

materials taken by CANMET.

The situation can be summarized as follows. NRC is active in basic research in chemistry of reactions of cement, admixtures, aggregates, and aggressive agencies. CANMET undertakes applied research in aggregate and concrete technology, including testing methodology, use of materials conducive to resource and energy conservation, and studies on durability of concrete under severe exposure conditions.

Another way of looking at the situation is to say that NRC is concerned almost exclusively with cement while CANMET deals with the structural material in which cement interacts with aggregate, i.e. with concrete and with the behaviour of concrete in service.

On the question of liaison between the various Federal groups, one has to say that PFRA seems too isolated from the others and is not familiar with their work. This is probably not very serious in view of PFRA's minimal involvement in the construction materials considered.

Since both NRC and CANMET are located in Ottawa, there should be no difficulty in effecting sufficient

liaison. However, at NRC it was felt that the annual meeting between NRC and CANMET should be more formal. The more frequent exchanges of information at the personal level, although useful, were thought to be too casual for careful co-ordinated planning of research and exchange of results. I am not sure that is a valid point in view of the virtually completely different type of work in NRC and in CANMET. NRC's attitude seems to be that its mission is "scientific research", rather than work which has immediate application to concrete practice; this, of course, is consistent with the background of many of the NRC staff members and is perfectly valid and valuable.

Some of CANMET's work is continued and developed locally for use in Provincial specifications or applied to utilization of local materials. It was CANMET that introduced research on superplasticizers to Canada, and others continue the investigations.

The last statements concern follow-up of CANMET's work but do not suggest that its work is a duplication of work done elsewhere. Indeed, without exception, no one viewed CANMET's work as overlapping with research done anywhere else in Canada. This is

so even in fields of study pursued widely, such as use of fly ash or durability of concrete, since CANMET takes the broad approach while others take a narrower user's point of view of the scope of the work to be done.

CHAPTER 8

CURRENT CANMET PROJECTS IN CONSTRUCTION MATERIALS: EVALUATION, TRANSFER OF RESULTS, AND CONTRACTING-OUT POLICY

This topic is really divided into three parts:

First, I was asked to examine the relevance and effectiveness of current projects at CANMET in construction materials of mineral origin in terms of the needs of the country.

Second, I was to determine if there is a satisfactory mechanism of transfer of technology of the research being done at CANMET.

Third, I was to determine if sufficient research and development work is being contracted out to meet CANMET's objectives in terms of "make and buy" policy.

Part 1

To the question, asked of those interviewed, "Is the work of CANMET relevant and effective?" the

answers were almost all in the first instance in the affirmative.

Looking at the universities first, I found that five described the work of CANMET as both relevant and effective and, indeed, "excellent". One thought that it was relevant and *slowly* became effective since research findings are not quick to percolate to those in the field. Two others described CANMET's work as "useful" and added that therefore it should be extended.

Some other professors were more specific. One pointed out that some of CANMET's work such as the ring test had really not become accepted, although others felt that the work on accelerated testing was good and this had been proved by the development of a Canadian Standard, the first in the world, based in part on this work. In one university in the West, CANMET was described as having a "low profile", although whether this was the fault of CANMET, or of the research worker, was not clear. This same person felt, however, that CANMET's work on non-destructive testing was useful and the conference on concrete in a marine environment had also been helpful. He did not think that the work on superplasticizers and

sulphur concrete had been useful, agreeing with one other professor that some of CANMET's work can be "too applied", somewhat "unplanned", and not carried to a "high enough level". Yet another professor, however, was sure that industry used the work of CANMET and found the bias towards applied research very helpful. "CANMET", he said, "benefits industry by picking-up topics like superplasticizers and adapting them to Canada". At NRC, the comment was made that CANMET has "a good interaction with industry".

This point of view was certainly supported unanimously by those members of industry who were interviewed. All found the work of CANMET relevant and useful with one exception: the Director-General of the Centre for Research and Development in Masonry was not familiar with the work of CANMET and he felt that CANMET did not know much about his organization. However, he added that his field is somewhat remote from that of CANMET's interests. The members of industry commented that CANMET's work is "relevant, effective, practical, useful", that it is on good topics, and that it achieves a great deal. One person stated that CANMET has become a "place of expertise" for Canada - and he added that it is especially satisfactory that information from CANMET is <u>free</u>.

Topics which were thought to be particularly useful were also mentioned. These were in the areas of work on blastfurnace slag and non-destructive testing and on concrete used at high temperatures. This latter topic had been relevant to an aluminium refining plant near Montreal. It was pointed out that no one else in Canada had tried to introduce superplasticizers and that it was entirely due to CANMET that something about their use was now known in Canada. The interesting comment was made that CANMET gives "useful engineering data" for chemists working on products for the construction industry.

The Provincial agencies (for convenience, this group includes PFRA) were nearly all in accord on the usefulness, effectiveness, and relevance of the work of CANMET. Several agencies mentioned that the work of CANMET on aggregate, fly ash, and blastfurnace slag had a direct "spin-off" for their use. One other agency found CANMET very useful to consult on the telephone and to use as a "sounding board" for ideas or for problems, although this interviewee did add that when he asked CANMET to do some work for him they were too slow for his needs since he usually has rather pressing problems. Another felt that CANMET was not helpful for the rather specialized work of his agency although he did find the information

on aggregates, "maybe superplasticizers", and the CANMET report on strength and freeze-thaw characteristics of concrete incorporating granulated blastfurnace slag useful. The conference on concrete in a marine environment he also found helpful but development of testing techniques by CANMET had not been useful to him personally.* In general, he, like one or two of the professors, considered CANMET's work to be insufficiently "basic" for his needs, but he acknowledged that CANMET is not really able to undertake basic research. Indeed, to do so would, perhaps, cause overlap with the universities or NRC. CANMET, itself, makes the simple statement that it just does not have sufficient funds for open-ended research.

In evaluating the work of CANMET, it may be useful to refer to the opinions of the National Advisory Committee on Mining and Metallurgical Research expressed at its fifteenth meeting in 1980. That Committee considered the work of CANMET in the fields of aggregate, cement, and concrete to be of very significant industrial relevance because of the depletion of conventional raw materials. It was thought that the mission orientation of the approach of CANMET had been adequately validated by commercial assessment. The rationale for the research was sound,

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* Nevertheless, CANMET's work on new testing techniques must be generally useful for it is explicitly referred to in ASTM (C803-79), British (CSB/39) and Canadian (A23.2-10C) Standards.

particularly for the use of marginal aggregates and cement replacement materials such as fly ash and blastfurnace slag. The use of the latter clearly meant a reduction in the energy required to produce a given volume of concrete. The Committee further commended the work being done on durability of concrete in acidic waters, on high-strength concrete at elevated temperatures, and on in-situ testing, but not on durability of concrete in sea water, nor further work on sulphur-impregnated concrete.

The Advisory Committee also expressed views on work to be done in the future. This should include studies of marginal aggregates, including slags, and use of cementitious materials such as fly ash and slag in the production of blended cement or directly in concrete. The general subject of future research in Canada is considered in Chapter 9.

In all, the findings were overwhelmingly in agreement that the work of CANMET is effective and relevant, especially with regard to industry. Any criticisms came, in the main, from those engaged in basic research themselves or from those with rather specific responsibilities and problems. The general

response was that CANMET benefits the construction industry throughout Canada and deals with nation-wide problems.

Part 2

The question regarding the effectiveness of the mechanism of transfer of technology of research being done at CANMET produced some variety in responses. Fourteen people from all types of institutions engaged in long-term research stated unequivocally that transfer of research to technology was "good", "very good", or "excellent". In many instances, the effective modes of transfer were cited, and these are listed in Table 8a. The numbers from each category of institution were fairly evenly distributed.

Under 'publishing' some of those interviewed distinguished between more general review work such as the book on non-destructive testing published by ACI (which was very useful) and research papers. Nevertheless, it was suggested that more could be published through ACI and other journals.

Table 8a: Numbers of people citing effective means of transfer of technology of research used by CANMET

Number of interviewees citing	Method of dissemination			
	Publishing	Codes and standards	Personal contacts with CANMET	Meetings and symposia
22	10	2	3	7

The comments on the work publicized through Standards made the point again that the inclusion of research results in Standards is absolute proof of effective transfer of technology of research. It was stated that here CANMET has been more effective than the universities with their NSERC sponsored research.

There was a number of comments with regard to publications which offered suggestions for change or improvement. We should perhaps remember that dissemination of information, while the prime responsibility of the 'producer', also involves some effort on the part of the 'receiver'. Sometimes, I gained the impression that the recipient of information felt that it should fall on his desk and the only effort he should have to make would be to pick it up.

However, many comments were very helpful and positive. It was suggested that CANMET should widen its mailing list and send a twice-yearly newsletter informing readers about on-going research as well as giving some idea of plans for the future. This might help co-ordination of research in other institutions and help their planning too. It was also suggested (by a professor) that knowledge of CANMET's "negative results" might be very interesting

and prevent some travelling of unproductive research by-paths.

Some of those responding felt that other types of publications should be used. Apparently CANMET's work is not mentioned in the publications of the Roads and Transportation Association of Canada, and it seems that some people engaged in research work on transportation read mainly this material. A suggestion was further made that Canada needs a Canadian concrete publication to improve communication within the construction industry in Canada. The publication by NRC of the bilingual quarterly *Canadian Journal of Civil Engineering* perhaps in part fulfills this need for French- and English-speaking Canadians. CANMET's influence is apparent in that Mr V. M. Malhotra, Head, Construction Materials Section is one of the associate Editors of the Journal. A further suggestion was that many contractors, and even consultants, do not read the research journals, and so publication in the bulletins of the Engineering Associations would help them to learn of CANMET's work.

With regard to meetings, the point was made that these should be used to publicize (as opposed to publish) CANMET's ongoing work, its plans for research

in general and for the future, and what contracts it is thinking of offering. More meetings on wider topics dealing with concrete were asked for, and here the conference on "marine concrete" was cited as being "very useful". Another suggestion made in a Prairie Province was for more regional meetings organized by CANMET.

Summing up, it may be useful to quote some general comments. One, from the Minutes of the Fifteenth Meeting of the National Advisory Committee on Mining and Metallurgical Research, notes that "The committee was impressed with the project leader's approach to technology transfer, and there appeared to be a correspondingly good feedback system." This is echoed by the head of department of a Provincial agency who said, "CANMET can't do more than publish its research work, answer queries, and be involved in conferences."

Possibly, however, some ideas in the previous paragraphs could be considered to give even wider dissemination of CANMET's work. In the United Kingdom, for example, a good method of spreading "Concrete Research News" is provided in the *Magazine of Concrete Research*. This magazine accepts items describing research

just starting, or entering a new phase, and gives briefly the background of the work, range of variables that it is intended to test, and names the people carrying out the work. Items are accepted at any time and are published as soon as possible. Institutions such as universities, polytechnics, and the Cement and Concrete Association take advantage of this service, which is thus of general help to all research workers in the field of concrete. An example of "Concrete Research News" appears in Appendix F.

Part 3

CANMET, in the two years 1979-80 and 1980-81, contracted out work to the value of $113,000. This was distributed as follows: $25,000 to University of Calgary, $50,000 to University of New Brunswick, $12,000 to Queen's University, $11,000 to Laboratoire de Béton, and $15,000 in small contracts. The contracts are all primarily for specific investigational work and only rarely include development.

The value of CANMET contracts in 1980-81 ($75,000) compares with the sum of approximately $3,000,000 awarded in operating and equipment grants to all projects (235

in number) in civil engineering in 1977-78 by NSERC. It is difficult to estimate how many of the projects would be in the area of concrete, cement or aggregate. Amongst the projects in civil engineering listed under the letter 'A' in 'Grants to Individuals', only one (Aïtcin) out of seven fell into one of the above categories. From information obtained from interviews (see Tables 4a, 5a, and 6a) it does not seem that, in 1980-81, NSERC supported many projects in the field of concrete as a material.

To the question of whether sufficient work is being contracted out by CANMET to meet the objectives of its "make and buy" policy, the responses were very varied. Table 8b shows a fairly clear pattern. The Provincial agencies are not and, in general, cannot be, involved in research for CANMET as they are already heavily committed to their own work. Universities and industry both do work for CANMET and would like to do more.

There was further comment on this: in the universities, it was, typically, felt that CANMET could contract out more to encourage development elsewhere. Some work (for example that on durability and alkali-aggregate reaction), it was thought, is

Table 8b: Responses to contract work awarded by CANMET

Institutions citing	Number of people responding		
	Not involved	Satisfied with type of contracts	Would like to be more involved in contract work
Universities	1	2	5
Provincial agencies	5	-	2 (but 1 sees difficulties)
Industry	1	2	4 (especially in winter when less construction is in progress)

better done by contracting out, although a rider was added that the universities prefer higher-level research projects and should not just follow well-defined work statements.

Industry thought that contracting out by CANMET should be to different geographical areas and felt that it was important to receive contracts to "educate and train" industry in testing and research. Contracts would also encourage industry to buy better equipment for these purposes. Here, industry criticized universities because of "undercutting" on contracts. Universities (because of 'hidden benefits' in equipment, premises, heating and overheads and in technicians' work sometimes paid for by the institutions - see Chapter 5), in consequence, charge, it was asserted, only about 25 per cent of the commercial rate.

More funds for co-operative research with CANMET could enable industry to conduct field tests to complement CANMET's own in-house research. However, it was strongly felt by industry that CANMET should do its own research as well as contract out. By this means, CANMET co-ordinates research, maintains continuity, and keeps research progress coherent. As well, it keeps an authoritative position in the

overall research scene. Industry felt that this was important so that research work did not become too theoretical – as it could do if left to universities working on NSERC contracts.

Universities, too, thought that CANMET should maintain a balance between contract and in-house work. Indeed, two professors said that they thought that the in-house work of CANMET should be extended but one added that this should only occur if specialized staff could be appointed. If this were not possible, contracting out was a better solution.

The Provincial agencies, by and large, echoed these arguments. One agency thought that perhaps CANMET should do the long-term research while contracts were used for short-term work but it was agreed that in-house work was very important so that CANMET retained control of the work and gave continuity to it.

The contracts that I saw were clearly written and stated explicitly the work to be done and the estimated cost. The research must be done exactly according to "the work statement" so that CANMET can rely on results from its contract research and

incorporate them in good faith in its reports and reviews. These are generally written by staff of CANMET with the persons who undertook the contract work as co-authors.

Whether or not sufficient work is being contracted out by CANMET is hard to say. Clearly, more people would be glad, for a variety of reasons, to undertake work for CANMET. This should not be too much in excess of in-house research done by CANMET or there will be a lack of balance and the very important controlling rôle of CANMET will be lost. If money is made available for more contract work, this important point should not be lost sight of.

To summarize, in my view the level of in-house activity of CANMET should be fully maintained in order to have one research centre with a continuous and coherent program. (In a more healthy economic situation, I would suggest a small expansion.) Contracting-out should be expanded, say doubled; the cost of this would be quite small and the advantages of encouraging industrial research and developing centres of research activity, considerable.

CHAPTER 9

AREAS OF FUTURE RESEARCH AND TECHNOLOGICAL STUDY FOR CANADIAN CONDITIONS AND FOR ENERGY CONSERVATION

Part 1

In this part, it is proposed to list areas of needed research in aggregate, cement and concrete particularly relevant to Canadian climatic and geographical conditions, as suggested by the various persons interviewed.

CONCRETE

A. Cold Conditions

I. Concrete in a cold climate

a) Effect of very low temperatures on the properties of concrete

b) Temperature differentials in different parts of the structure

c) Freezing and thawing of different concretes

d) Construction in winter conditions

(i) temperature differentials during construction

(ii) effect of frost on fresh concrete

(iii) determination of a reliable minimum temperature for placing concrete

(iv) in-situ strength testing to know when to post-tension and to slip formwork

(v) non-destructive testing, including pull-out test, to optimize mix proportions of concrete to be placed in winter

II. Concrete in a cold marine environment

a) Investigation of the maximum C_3A content of cement for use in sea water

b) Off-shore platforms in Arctic waters

(i) use of local Nova Scotia aggregate

(ii) effect on the concrete of cold water outside and warm oil inside the structure

(iii) finishing concrete

(iv) repair of concrete

(v) ensuring cover to steel

III. Concrete in containers for cold or hot materials

a) To transport and store natural gas

b) To transport and store other cryogens

c) To transport and store hot oil

d) To investigate the use of local aggregate for uses in a), b) and c)

e) To consider the problem of temperature differentials between the inside and outside of the structure

B. Durability

I. Concrete in aggressive environments

a) De-icing salts and acid rain: effect on airfields (military and commercial), bridge decks, parking garages

b) Protection of concrete from salt

c) Use of corrosion inhibitors or epoxy coated reinforcement

II. Deterioration

a) By salt and acid rain (see BIa)

b) Of marine concrete (see AII)

c) Of concrete in a cold environment (see AII)

d) Diagnostic methods of investigation of failures and of residual strength, including condition of the steel

e) Investigation of causes of long-term deterioration of concrete made with

AGGREGATE

A. Sources of Aggregate

I. Shrinking source of supply (old sources used up, spread of cities, environmental protection)

a) Survey of availability of aggregate

b) Investigation of type of rock which can be crushed for use as sand

c) Study of marginal aggregates

(i) aggregates with organic impurities found in the North

(ii) aggregates from the interior of British Columbia (friable, alkali-reactive, absorptive)

(iii) aggregates with other deleterious substances

d) Increased use of low-quality aggregate in some concrete for which standard aggregates are unnecessarily "good"

e) Transportation systems for aggregates which may now have to be brought longer distances

II. Economic production of lightweight aggregate which is needed by the construction industry

B. Alkali-Aggregate Reaction

1. Development of a "valid" alkali-aggregate reactivity test

II. Study of increase in alkali-aggregate reaction in concrete due to higher cement content in concrete

III. Study of increase in alkali-aggregate reaction due to use of more marginal (more reactive) aggregates

IV Study of increase in alkali-aggregate reaction due to increased alkali content in cement

C. Coating of Aggregate

I. For frost protection

a) New techniques for coating

CEMENT

A. Fly Ash and Pozzolanas

I. Investigation of fly ash (in use with insufficient back-up information)

a) Use in air-entrained concrete

b) Strength gain in concrete made with fly ash

c) Curing conditions necessary for concrete made with fly ash

B. Impact of Cements with more C_3A and C_4AF

(Developed because more iron is used to lower the kiln firing temperature)

Part 2

In this part, are listed the Technical Opportunities for research in construction materials in areas of resource and energy conservation, as perceived by the various persons interviewed.

CONCRETE

A. Insulation and Heat Loss

I. Development of lightweight concrete to utilise its thermal properties in structural applications

II. Improvement of thermal properties of concrete walls

III. Investigation to determine whether fresh concrete may be *over* protected in cold weather with a corresponding waste in heat

B. Reducing Amount of High-Quality Concrete

I. Study of use of composite construction of walls with smaller mass of concrete per unit area

II. Study of the durability of lean concrete with a view to its greater use

C. Incorporating Waste Materials in Concrete

I. Continue work on sulphur-impregnated concrete to optimize sulphur content

II. Blastfurnace slag concrete .

a) Improve rate of hardening

b) Study freeze-thaw characteristics

AGGREGATE

A. Using Waste Materials

I. Recycling old concrete as aggregate

II. Use of slag from electric furnaces for aggregate (high CaO content)

a) Use of aggregate in AII for autoclaved block

B. Energy Savings

I. Utilization of marginal aggregates to reduce transportation costs

II. Study of method of production of crushed rock, coarse aggregate and sand

a) Relation between type of crusher and type of rock with a view to optimizing use of energy in production

III. Secondary use of mine space for underground aggregate excavation and stock-piling

CEMENT

A. Use of Waste Products

I. Use of fly ash combined with cement

a) Study of freeze-thaw characteristics of resulting concrete

b) Improving the rate of hardening of concrete made with fly ash

II. Kiln dust utilization

III. Use of supplementary waste fuels for cement manufacture (e.g. garbage, hog fuel, used lubricating oil)

B. More Efficient Production

I. Reduction of heat loss from kiln

a) Heat exchange systems

b) Better kiln insulation

II. New processes of manufacture

III. Better grinding and classification of cement to avoid particles smaller than 3 μm and greater than 30 μm

C. Reduction in Quantity of Cement Used

I. Improved activation of cement by chemical and mechanical means during mixing

II. Use of additives

a) Superplasticizers

b) Limestone dust (up to five per cent)

c) Pozzolanas (fly ash and others)

Part 3

It is difficult to arrange the above, rather extensive, lists in order of priority as, clearly, specific economic and even political factors would play a rôle. However, in a general manner, the following observations can be made.

e) Deterioration of concrete due to de-icing salts is extremely expensive. Industry has no interest in combating the problem - only the government can do so.

f) The durability of concrete in cold waters has to be investigated prior to large-scale construction. These projects are of interest to the government, and it should insist on early studies.

g) Techniques of winter concreting should be the responsibility of the construction industry.

It seems thus that the *main* areas of needed research particularly relevant to Canada and to resource conservation and energy savings are as follows.

A) Concrete

a) Durability of concrete in cold inland and sea water

b) Durability of concrete in bridges and parking garages (1)

(1) The US Federal Highway Administration estimates that $US 6.3 billion was needed in 1978 to restore bridge decks in the federal highway system. Thus even small improvements in durability of concrete can produce significant savings.

a) Improvement in cement production with respect to energy is the responsibility of the cement manufacturers.

b) Developments conducive to the use of less cement in concrete and use of non-kiln-fired additives in cement and in concrete are not in the interest of cement manufacturers. Research in these areas needs therefore to be done or sponsored by government agencies.

c) The aggregate industry consists of units that are too small to undertake any research. Reckless exploitation of existing sources, regardless of whether "good" or inferior aggregate is adequate in a given case, will inevitably lead to shortages in the future. Assessment of various aggregates, including marginal and poor ones, is needed now. The basis for their use needs to be established by government agencies.

d) Because the construction industry, unlike the manufacturing industry, does not rely on product competition, there is little scope for research leading to resource or energy economy. Therefore, the government must provide a lead in developing new techniques and technologies.

B) Aggregate

a) Use of marginal aggregates

b) Use of waste materials as aggregate, (2) including development of economic production of lightweight aggregates

C) Cement

a) Use of *Canadian* fly ash (3)

b) Use of blastfurnace slag and of additives to cement in general in order to reduce the consumption of cement (4)

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(2) Slag from electric furnaces (which has a high C_aO content) made into aggregate for use in autoclaved block appears to be a proposition well worth investigating.

(3) Fly ash and blastfurnace slag have to be studied using the *particular* materials with the *actual* cement to be used: general studies or studies abroad are not adequate for local validity and application.

(4) Cement manufacture is responsible for about 3.6 per cent of total industrial energy consumption

CHAPTER 10

COMPARISON OF APPLIED RESEARCH EFFORT IN CANADA WITH OTHER COUNTRIES

Before a comparison of effort and expenditure on long-term applied research in the fields of cement, aggregate and concrete in Canada and in some other industrialized countries can be made, estimates of total expenditure on such research for each country are needed. These are not readily available.

Let us first deal with Canada. One approach is to use figures obtained in the present study and reported in Tables 3a to 6a. These give the following expenditure on long-term applied research in 1980:

Federal agencies	$651,000
Universities	$577,000
Provincial agencies	$947,000
Industry	$1,296,000
	$3,471,000

Allowing for organizations which have not reported, but also bearing in mind the double reporting of some contracts (e.g. CANMET and universities) and some "optimistic" or "over-enthusiastic" estimates, the total figure for Canada is, at most, $4.5 million. This expenditure should be viewed against the value of cement production of $650 million (estimated), the value of construction of $50,000 million (estimated) and GNP of $300,000 million (estimated).

Another estimate is that due to W. G. Plewes, formerly Senior Research Officer in the Division of Building Research of the National Research Council, from whose work Table 10a is derived. Since the information supplied by some organizations was confidential, detailed description or classification is not available. Plewes' data were obtained in 1969 but there is no reason to believe that any radical change has taken place since, as demonstrated by the data for 1975, even less detailed, given in Table 10b.

For present purposes, the relevant figure of R & D expenditure from Plewes' report is that given in column 3 of Table 10a, viz. $574,000. Allowing for some expenditure which escaped Plewes, we can

Table 10a: Estimated annual expenditures on research in cement and concrete in Canada in 1968 (after W. G. Plewes)

Source of funds	Category				All categories	Percentage of total
	1	2	3	4		
	Thousands of dollars					
NRC university grants	86	7	7	220	320	20
NRC industrial research program						
a) NRC contribution	26	33	23		82	5
b) industry contribution	25	30	32		87	5
NRC in-house	216	162	12	77	467	28
Federal government (other than NRC)		70		80	150	9
Public utilities	10	30	25	85	150	9
Highway departments	42	85	2	32	161	10
Provincial research councils		7	8		15	1
University funds				18	18	1
Municipalities		100			100	6
Industry	15	15	15		45	3
Industry associates		35	1	2	38	2
Others				9	9	1
TOTALS	420	574	125	523	1,642	100

Category 1: Fundamental research on cement, cement paste and concrete

Category 2: Evaluation of physical and mechanical behaviour of concrete as related to specific applications and problems.

Category 3: Development and improvement of construction techniques and methods.

Category 4: Structural theory, analysis and design

Table 10b: Estimated annual expenditures on research in cement and concrete in Canada in 1973 (from Department of Industry, Trade and Commerce)

Source of funds	Thousands of dollars	Percentage of total
Federal Government		
NRC university and IRAP grants	350	12
NRC in-house	400	13
Department of Industry, Trade & Commerce (PAIT & IRDIA)	250	8
Department of Energy, Mines & Resources - in-house	200	7
Provincial governments		
Public utilities	500	17
Highway departments	500	17
Provincial Research Councils	100	3
Municipalities	200	6
Industry	500	17
TOTAL	3,000	100

take the sum of $600,000. This sum should be considered in relation to the value of the production of cement in the same year of $152 million, the value of construction of $12,214 million and GNP of $72,586 million.

A like analysis for concrete research and production in 1973 does not yield significantly different data. An estimate of the research expenditure is given in Table 10b. Deducting the expenditure on basic research and on routine testing, the research expenditure is, say, $1.5 million. The cement production for the same year is $242 million, the value of construction $20,174 million and GNP $120,438 million. The present situation, allowing for inflation, is similar except that the expenditure by the Department of Industry, Trade and Commerce is smaller and by industry itself larger.

All the figures quoted are in current dollars.

The figures for construction include of course materials other than concrete, so that relations of R & D expenditure to the value of cement and to GNP are most appropriate. These are, as follows:

Year	Long-term applied R & D	Value of cement	GNP	Ratio (1):(2)	Ratio (1):(3)
	$ thousand	$ million	$ billion	per cent	per cent
	(1)	(2)	(3)		
1968	600	152	72	0.4	0.0008
1973	1500	242	120	0.6	0.0016
1980	4500	650 (est)	300 (est)	0.7	0.0015

Unfortunately, figures for other countries are not available in the same form. For the U.S. only the expenditure on *basic* research by the cement industry can be quoted. According to the report of the U.S. National Materials Advisory Board prepared in 1980 for the U.S. Department of Defense, less than 0.03 per cent of gross sales of cement is spent on basic research. Related to the value of concrete, the figure is even smaller: 0.01 per cent. The report finds the R & D expenditure in U.S. to be inadequate and predicts a long-term ill-effect on the cement and concrete industry. It should be emphasized that the above are *not* figures for applied long-term research; these do not seem to have been published.

It can be added that R & D at the Portland Cement Association in U.S. has been decreasing: in

1978, its value was 74 per cent of that in 1960, and only one-quarter of the 1978 figure was supported by industry; the rest was contract work, not necessarily in the field of cement and concrete. In Canada, research expenditure by the cement industry incurred within Canada is very small.

In contrast, the report of the U.S. National Materials Advisory Board states that in 1976, eight major Japanese contractors spent $US 43.5 million on R & D. In addition, funds were provided by the Japan Building Contractors Society and by the Japanese government.

In the United Kingdom, long-term applied research is carried out by several categories of bodies. The first of these is trade associations such as the Cement and Concrete Association (financed by the cement manufacturers), Sand and Gravel Association, British Quarrying and Slag Federation. The annual expenditure by this group, excluding that on technical literature and other dissemination of information is of the order of £8 million, i.e. $22 million. This figure does not include research by the cement industry on its own manufacturing

problems which amounts to about £3 million, i.e. £8 million.

The second category of bodies carrying out long-term applied research is the construction industry. The Construction Industry Research and Information Association spends about £300,000 or $800,000 on concrete problems. Moreover, many large contractors have very extensive laboratories of their own and they carry out there long-term research for major construction projects and other developments. The expenditure incurred by them is very likely $1.5 million.

In addition, several government laboratories, such as the Transport and Road Research Laboratory and the Building Research Establishment pursue long-term applied research in the fields of concrete and aggregate. Many universities and polytechnics are also active in concrete research, although less so in cement and aggregate.

A very rough estimate of *all* the above research expenditure would be $28 million. This represents about 1.5 per cent of the value of the cement production or about 0.0045 of the value of GNP.

In France, much long-term applied research is carried out by trade and semi-public research organizations which are financed by a levy. This is 0.3 per cent of the value of cement and about 0.3 per cent of the value of ready-mix concrete; there is also a levy on aggregate. Bearing in mind that research monies spent on cement, aggregate and concrete *all* represent expenditure which can be related to the value of the cement involved, the research expenditure by these bodies amounts to about 1.3 per cent of the value of the cement . Adding research done by the government, universities, and other bodies, a figure of 1.5 per cent seems realistic. Related to GNP the research expenditure is about 0.0063 per cent.

Thus, for the three countries considered, the *approximate* figures for long-term applied research in cement, aggregate and concrete in 1980 are as follows:

	Canada	UK	France
Research as percentage of value of cement production	0.7	1.5	1.5
Research as percentage of GNP	0.0015	0.0045	0.0063

In summary, a simple and direct comparison between Canada and other countries is not easy. It seems, nevertheless, that the Canadian effort is, at best, about one-half of that in France and in the United Kingdom on the basis of research expenditure per value of cement produced and one-third or less on the basis of GNP. The distribution of research effort between various types of bodies in each country is different, being related to the existence of traditional trade and government bodies.

This situation is of interest in relation to the view expressed by the National Advisory Committee on Mining and Metallurgical Research that in Canada the performance of R & D in government is perhaps somewhat higher, in universities about the same, but in industry very much lower than in comparable countries. The problem of how to encourage industry is a difficult one: some comments on it will be made in the next chapter.

CHAPTER 11

CONCLUSIONS

The value of building materials has always formed a substantial percentage of the total value of construction. For example, in 1977, the total value of all materials employed in construction in Canada amounted to $13.5 billion. Concrete represents a large part of this sum, and this means a large need for Portland cement, or additives to it, and for aggregate. A judicious choice and use of these materials can result in considerable energy and resource savings. Since aggregates and waste materials vary enormously, a study of their *actual* properties is necessary; reliance on research done elsewhere is not possible. The same applies to many durability problems. In other words, Canadian materials to be used in Canada have to be studied in Canada. And, since the issues are those of materials of mineral origin and of energy, CANMET seems an appropriate agency to undertake the necessary long-term applied research.

At this stage it may be appropriate to ask the question: who is the customer for CANMET's research?

First, Federal and Provincial governments, because the public sector is a large purchaser of concrete and it is therefore in the public interest to exert influence on the cement and concrete industries and to encourage them in R & D activities.

Second, the aggregate industry, because it consists of enterprises which are too small to do any research of their own, and it is in the national interest to optimize the use of this mineral resource.

Third, the concrete and construction industries, because, unlike manufacturing industries, they are not based on product competition and perceive no benefit for themselves in research whose results are available for all to use.

One can add at this stage that applied research on "old" and well-established materials like concrete and aggregate has no glamour attached to it, nor is it politically exciting, yet such research is vital. Who, then, is to do it?

Research work done by isolated individuals and small groups can clearly be of great value. Many of these people are in universities and, because

they depend on graduate students whose time span at the university is between one and three years, really long-term projects are rarely pursued.

Moreover, the solution of many broad or complex problems requires several people with varied expertise who are available on a full-time basis. This is possible in a research laboratory, be it in a large contracting firm, be it in an industrial research organization, be it in a government agency. In industrialized foreign countries, one or more of these exist: in France, the trade research associations have excellent and well-staffed laboratories; in the United Kingdom, several contractors each have permanent large laboratories which undertake long-term R & D; in West Germany, the various provinces (Länder) support materials testing laboratories, usually associated with universities, which carry out long-term investigations.

In Canada, unfortunately, Provincial government laboratories are, with probably but one exception, non-existent. The same applies to Crown corporations. There are no large contractors, and therefore, with one very recent exception, no laboratories. There is very little research activity in trade associations, except for the cement manufacturers. For the most

part, they do their research in the US, or possibly in the parent company abroad, or not at all.

And yet concentrated expertise in the field of cement, aggregate and concrete needs must exist in at least one centre in the country. CANMET is the only place available, albeit on a modest scale, and continuation of its work, and indeed an expansion, seem highly desirable. In addition to in-house work, in order to encourage development of local facilities and expertise, contract work is also desirable. My conclusion is therefore that both in-house and contract-work should continue with initially enhanced funding. With time, industry should be expected to support work in the various laboratories direct.

The argument about having in the country a "centre of excellence" in applied research on materials of mineral origin is important. Being such a centre, CANMET could participate in international cooperative research programmes on energy conservation such as that of the International Energy Agency, which is seeking CANMET's collaboration in the field of use of waste materials in cement.

There is no doubt that CANMET research programmes are already contributing to the advancement of construction technology and aiming for savings in both energy and materials. In the opinion of the National Advisory Committee on Mining and Metallurgical Research, expressed at its 15th meeting, "CANMET should seriously consider a planned expansion of the program to establish a nationally accepted centre of excellence".

This centre would improve its rôle in providing continuity and general direction of research. It should also contract-out work. The old adage that nothing succeeds like success applies to research and development, too. If a reasonable amount of work is done in Canadian laboratories so that they can be assured of long-term projects and continued flow of work, they could develop facilities and expertise for tackling future problems. Without such an assurance, laboratories cannot flourish and cannot respond speedily and effectively to demand.

Finally, I should like to repeat the vital point: there is a considerable scope for energy economies through better use of concrete and of aggregates, especially from waste materials. While many "look" at the various problems, active leadership is essential and it seems that only CANMET can provide this.

All this development will undoubtedly be good for Canada and it will also enable Canada to give a lead to the world in those fields where cold weather and durability issues are present.

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APPENDIX A

LIST OF PERSONS INTERVIEWED AND CONTACTED

ORGANISATION	LOCATION	NAME	POSITION
British Columbia Hydro and Power Authority	Vancouver, British Columbia	Mr E.G.W. Bush	Contracts Preparation Section Hydro-electric Generation Projects Division
British Columbia Ministry of Transportation and Highways	Vancouver, British Columbia	Mr B.W.R. Eastman	Regional Geotechnical and Materials Engineer
	Victoria, British Columbia	Dr D.R. Haughton	Special Projects Engineer, Geotechnical and Materials Branch
Canada Cement Lafarge Ltd	Montréal, Québec	Mr R.W. Suderman	Manager, Research Laboratory and Quality Control
		Mr H.L. Isabelle	Manager, Technical Sales and Product Development
		Mr M. Nisbet	Assistant to Vice-President, Major Investments
Canada Centre for Mineral and Energy Technology	Ottawa, Ontario	Mr V.M. Malhotra	Head, Construction Materials Section, Mineral Processing Laboratory
		Mr W.A. Gow	Chief, Mineral Sciences Laboratories
		Mr V.A. Haw	Deputy Director General, CANMET

Canadian Portland Cement Association	Halifax, Nova Scotia	Mr N.F. MacLeod Mr M.J. Burke	Regional Manager Senior Field Engineer
	Ottawa, Ontario	Mr S. Cumming	Manager, Engineering Services
	Vancouver, British Columbia	Mr R.W. Piggott	Regional Manager
Canfarge Ltée	Montréal, Québec	Mr V. de Benedictis	Assistant Director of Research and Development
Cement and Concrete Association	Wexham Springs, Slough, England	Dr R.E. Rowe	Director-General
Centre de Recherche Industrielle du Québec	Sainte-Foy, Québec	M F. Dugal M G. Auger	Directeur, Secteur matériaux et Procédés industriels Directeur, Service des communications
Centre for Research and Development in Masonry	Calgary, Alberta	Dr E.L. Jessop	Director General
Construction Industry Research and Information Association	London, England	Dr L.S. Blake	Director
Ecole Polytechnique Université de Montréal Departement de Génie Civil	Montréal, Québec	Dr J. Houde	Professeur titulaire
Hardy Associates (1978) Ltd	Burnaby, British Columbia	Dr D.R. Morgan	Manager, Materials Engineering Division

Hydro-Québec	Montréal, Québec	M G. Séguin	Chef de Division Contrôle béton Structures et Mecanique
Klohn Leonoff Ltd	Calgary, Alberta	Dr L.E. Rodway	Head, Materials Engineering Division
Laboratoire de Béton Ltée	Montréal, Québec	M A. Bisaillon	Président
B.H. Levelton and Associates Ltd	Vancouver, British Columbia	Mr P.T. Seabrook	Consulting Engineer
Manitoba Hydro	Winnipeg, Manitoba	Mr K.A. Lenz	Concrete Engineer
McGill University Department of Civil Engineering	Montréal, Québec	Dr M.S. Mirza	Professor
Ministère des Transports Laboratoire Central	Sainte-Foy, Québec	M J.R. La Haye	Directeur de la Recherche et du Contrô
		M G. Dallaire	Chef de la Division Sols, Agrégats et Textile
		M G. Fréchette	Chef du Laboratoire
Ministry of Transportation and Communications, Research and Development Branch	Toronto, Ontario	Mr P. Smith	Director
		Mr D.G. Manning	Senior Research Officer
		Mr A. Rutka	Principal Research Engineer
		Mr J. Ryell	Head, Concrete Section, Engineering Materials Office
National Boring and Sounding Inc	Montréal, Québec	Dr G. Haddad	Chief, Materials Control
National Research Council	Ottawa, Ontario	Dr V.S. Ramachandran	Head, Building Materials Section, Division of Building Research

New Brunswick Department of Transportation	Fredericton, New Brunswick	Mr G. Keenan	Assistant Highway Director
Nova Scotia Power Corporation	Halifax, Nova Scotia	Mr A. Douma	Manager, Civil Engineering, Thermal Engineering Department
		Mr G.F. MacKenzie	Civil Engineer, Thermal Engineering Department
Nova Scotia Technical University, Department of Civil Engineering	Halifax, Nova Scotia	Dr J.G. Potyondy	Professor
Ontario Hydro Research Laboratory, Civil Research Department	Toronto, Ontario	Mr J.N. Mustard	Manager
		Mr V.R. Sturrup	Supervising Engineer, Masonry Section
		Mr T.J. Carmichael	Geotechnical Engineer
		Mr P.K. Mukherjee	Engineer, Masonry Section
Prairie Farm Rehabilitation Administration	Saskatoon, Saskatchewan	Mr N. Peters	Chief, Geotechnical Division
		Mr J.R. Scoular	Concrete and Quality Control Engineer
Portland Cement Association	Skokie, Illinois	Mr M.J. Catani	Director, Building Division
Queen's University Department of Civil Engineering	Kingston, Ontario	Dr B.B. Hope	Professor
Research and Productivity Council	Fredericton, New Brunswick	Dr D. Abbott	Head, Department of Applied Sciences
Standard Slag Cement Co.	Fruitland, Ontario	Mr G.V. Phillips	Vice-President
Sternson Ltd	Brantford, Ontario	Mr N.P. Mailvaganam	Director, Research and Development
Trow Limited	Ottawa, Ontario	Mr J.A. Bickley	Vice-President

Université Laval, Département de Génie Civil	Sainte-Foy, Québec	Dr L. Lachance	Professeur titulaire
Université de Sherbrooke, Département de Génie Civil	Sherbrooke, Québec	Dr P.-C. Aïtcin	Professeur
University of Alberta, Department of Civil Engineering	Edmonton, Alberta	Dr J. MacGregor	Professor
University of British Columbia, Department of Civil Engineering	Vancouver, British Columbia	Dr S. Mindess	Associate Professor
University of Calgary Department of Civil Engineering	Calgary, Alberta	Dr M.A. Ward Dr R.C. Joshi Dr C.D. Johnston	Professor and Head of Department Professor Professor
University of New Brunswick, Department of Civil Engineering	Fredericton, New Brunswick	Mr T.W. Bremner	Professor
University of Saskatchewan, Department of Civil Engineering	Saskatoon, Saskatchewan	Dr K.W. Nasser	Professor
University of Toronto, Department of Civil Engineering	Toronto, Ontario	Dr G. Heinke Mr R.H. Mills Dr J. Timusk Dr S.M. Uzumeri	Professor and Chairman of Department Professor Associate Professor Professor
University of Windsor, Faculty of Engineering	Windsor, Ontario	Dr C. MacInnis	Dean
Warnock Hersey Professional Services Ltd	Montréal, Québec	Dr R. Farsky	Manager
N.G. Zoldners	Ottawa, Ontario	Mr N.G. Zoldners	Consulting Engineer

APPENDIX B

DESCRIPTION OF LONG-TERM APPLIED RESEARCH UNDERTAKEN BY FEDERAL GOVERNMENT AGENCIES

At the Prairie Farm Rehabilitation Administration (PFRA), Saskatoon, I saw Mr N. Peters, Chief, Geotechnical Division) and Mr J. R. Scoular, Concrete and Quality Control Engineer. Work here has been in progress for more than 20 years in the field of use of fly ash in concrete under sulphate attack and the project is still continuing. It is estimated that a further five man-years will be required for the preparation of the report which should give a comprehensive picture of the effects of a wide range of variables upon the sulphate resistance of concrete made using partial fly ash replacement and Types I and V cements.

Information on work done in the Division of Building Research at the National Research Council (NRC) was obtained from Dr V. S. Ramachandran, Head, Materials Section. The work done there is mainly in the nature of basic research but a brief mention may be interesting.

The topics covered include the mechanism of reactivity and basic properties of fly ash but the studies are not particularly concerned with the types of fly ash available in Canada. One of the objects of the work is to discover accelerators or catalysts for the hydraulic reaction of fly ash.

Work is also done on the basic mechanism of frost action and on the use of incorporated fine materials in lieu of entrained air. Some of the investigations on frost action include assessment of damage in parking garages.

Another topic is that of mechanism of attack of concrete by sulphates and chlorides. Studies are also made of mica-reinforced cement and on the development of new test methods for alkali-reactive aggregates. Work at NRC is done on admixtures, and on corrosion, particularly from the physical-chemical standpoint. Some of the data on corrosion of parking buildings are bought from outside bodies but NRC now monitors further progress of corrosion.

A list of general topics worked on at NRC would cover:

a) Basic properties of concrete

b) Durability to frost action in concrete and other porous materials

c) Performance of building materials as revealed by their microstructure and composition

d) Performance of concrete as related to the chemical processes in cements

e) Physical and mechanical properties of repair systems

f) Performance of Canadian aggregates

It is difficult to draw a line between the basic research element in the above work and research of an applied nature but all the work done is of a long-term character. The total expenditure is $800,000 per annum and the total effort represents 23 man-years. Probably 15 per cent of the total effort can be classified as long-term applied research, viz. 3.5 man-years and $120,000.

Information on work done at the Canada Centre for Mineral and Energy Technology (CANMET) was obtained from Mr V. M. Malhotra, Head, Construction Materials Section, Mineral Processing Laboratory and his staff. I also visited the CANMET laboratories.

The work of CANMET in the field of cement, aggregate and concrete can be briefly summarized as follows:

a) Durability of concrete in acidic and pure waters of Northern Canada. (This work is done in collaboration with Hydro-Québec and Société d'Energie de la Baie James and with Laboratoire de Béton (see Chapters 4 and 6).)

b) Effect of low temperatures on concrete, especially in relation to the length of the freezing cycle

c) Accelerated strength testing of concrete

d) Various pull-out techniques for in-situ strength determination

e) Performance of superplasticizers in concrete

f) Performance of high-alumina cement concrete

g) Measurement of thermal conductivity of concrete

h) Examination of Canadian fly ashes

i) Properties of Canadian lightweight aggregates

j) Assessment of coal mine shale for lightweight aggregate

k) Sulphur-infiltrated concrete

l) Long-term performance of concrete incorporating blastfurnace slag

m) Comparative sample program (with CSA and cement industry) to assess cement specifications and test methods

Some of these projects are, at present, in the stage of follow-up of a substantial investigation so that the time currently involved in them is minimal.

Some other projects have reached the stage of conferences dealing with dissemination of the research results obtained. Yet other projects are of a very long nature and the effort in any one year may be limited to taking readings on samples.

The above remarks will explain why a wide range of projects is done by no more than nine people with an annual expenditure of $450,000. It should be added that, because of the nature of the organization of CANMET, the Construction Materials Section has access to facilities and time of other sections. Thus the real effort is probably larger than reported.

APPENDIX C

DESCRIPTION OF LONG-TERM APPLIED RESEARCH UNDERTAKEN BY PROVINCIAL AGENCIES

Information about work done in the British Columbia Hydro and Power Authority was given by Mr E. G. W. Bush of Contracts Preparation Section, Hydro-Electric Generation Projects Division. The main activity is concerned with answers to specific field problems arising in the construction of various dams. This includes investigation of aggregate sources, studies of strain capacity, creep, autogenous volume changes, use of admixtures and of fly ash, and also thermal properties of concrete and efficiency of latex compounds for bonding and patching.

Some of the work is done in-house, and the rest by contract, mainly to the University of Calgary and R. M. Hardy Associates (1978) Ltd. The amount of work done fluctuates with the size, or indeed existence, of specific construction projects.

Mr K. A. Lenz from Manitoba Hydro wrote to me that Manitoba Hydro is not engaged in any long-term applied research relating to aggregate, cement or

concrete. Having stated the above, he went on to say that they are very interested in the long-term performance of the concretes in their many hydro-electric generating stations. Through their concrete surveillance and inspection program, they are attempting to correlate life expectancy and the need for present and future repairs, with a measure of the quality of the in-place concretes. Tests being performed on concrete cores recovered from various stations include air-void analyses, compressive strength tests and, in some cases, accelerated freeze-thaw tests.

Work done in the Ontario Hydro Research Laboratory, Civil Engineering Department, covers a wide range of topics. About 70 per cent of the work done arises from requirements of other branches of the Ontario Hydro, and consists mainly of testing and development of better techniques; 30 per cent of the work is initiated in the research laboratory itself but topics are discussed with other branches. Thus, not all their work comes under the heading of long-term applied research. There is relatively little collaboration with Hydros in other Provinces but some work, although not of long-term nature, is done with British Columbia Hydro. However, good contacts are maintained via technical committees.

Ontario Hydro has done some work on contract for CANMET, mainly in the area of superplasticizers and also on the use of fly ash in high strength concrete.

Much of their work is concerned with quality control and field and internal research programs for specific small projects. Thus, work done at Ontario Hydro covers a range of topics in the field of concrete and concrete materials. This includes the use of cement and cement grout to stabilise atomic waste fill, and backfilling of electric cables with cement stabilised fly-ash slurry. Temperature rise of cables in different types of backfill has been studied. Application of other types of backfill is being investigated. Other research work is concerned with temperature cycling in mass concrete in order to determine optimum mixes of a given strength; various cements and fly ash have been used. A conduction calorimeter has been developed at Ontario Hydro. Alkali-aggregate reaction is also studied.

Considerable work has been done on utilisation of fly ash but this has generally not been successful because of the variability in the quality of fly ash. Specifically, since the power stations are not used

for base load, the carbon content of fly ash is very high with the result that the fly ash cannot be used for air-entrained concrete. On the other hand, fly ash obtained in winter is of good quality but there are no possibilities of stocking it until use in the summer.

Fly ash was used in the past for the production of lightweight aggregate within the Hydro but this has proved uneconomical. Other topics include creep of fly ash concrete based on equivalent strength of concrete.

Information on work done at Hydro-Quebec was obtained from M. Gaëtan Seguin, Division Head, Concrete Control, Structures and Mechanics. Hydro-Québec is totally different from other Canadian Hydros in that it has no laboratories, does no testing (except on very small projects), and undertakes no research. The Hydro uses private testing laboratories whose work is described elsewhere in this report. One can therefore say that there is no long-term applied research undertaken in Hydro-Québec.

From the Ministry of Transportation and Highways, British Columbia, Dr D. R. Haughton wrote

to me about their development projects in cement, aggregate and concrete. He described generally two projects. The first concerns aggregate: its sources have been catalogued in terms of location, land use, surface and subsurface geology, quality and reserves. A further stage, now in progress, examines the physical, chemical and petrographic tests applied to aggregate, which are used to define its quality. This portion of the project will result in normalization of aggregate quality tests to a fundamental test such as the petrographic test. Geotechnical personnel from each of the six Ministry of Highways Regions throughout British Columbia will continue to provide input into this project.

The second project deals with high-alumina cement concrete. Here, the Geotechnical Branch, in conjunction with the Bridge Branch, Ministry of Transportation and Highways, is investigating the use of high-alumina cement concrete as a bridge deck overlay and also other uses where rapid hardening concrete is desirable.

Other aggregate projects undertaken by the Ministry of Transportation and Highways include joint development and operational pavement design

projects, including aggregate beneficiation and aggregate stabilization by chemical or physical means. Aggregate studies relating to the cause and correction of frost heave in highways are also being undertaken. Concrete investigations also include evaluation of latex concrete, the use of lightweight concrete, concrete surface treatments, and corrosion prevention concrete additives.

Since many projects involve both operational and remedial works with development implications, it is not possible to define expenditures solely related to development, but the long-term applied research is not significant.

Applied research in aggregate, cement and concrete is done at the Ontario Ministry of Transportation and Communications. Choice of research projects is made in-house but all the projects are related to practical problems relevant to the Ministry's operation. There is a research and development steering committee which contains people from the Ministry and this gives advice on the choice of projects, but it is not a committee which directly oversees the work.

Most of the research projects undertaken by the Concrete Technology group within the Research and

Development Branch are concerned with the durability of reinforced and prestressed concrete structures in the highway environment. The objective of several projects is to develop recommendations for changes in policies for the construction of new structures and the rehabilitation of existing structures. This involves undertaking research projects to monitor the performance of existing repair techniques, the development and implementation of improved repair methods and the transfer of the developed technology to the site personnel through the production of specifications, manuals and through seminars. It also involves developing alternative methods of improving the durability of new construction and repair procedures, investigating new materials, test methods and processes, and undertaking fundamental research studies in support of the above objectives. There are no active research projects on Portland cement.

A list of projects undertaken recently and still current is as follows:

1. Laboratory investigation of concrete overlays
2. Detection of concrete deterioration in asphalt covered bridge decks
3. Evaluation of demonstration projects - concrete bridge decks
4. Effect of waterproofing membranes on steel corrosion

5. Bridge deck restoration manual
6. Investigation and restoration of deteriorated substructures
7. Measurement of the electrical impedance of concrete (at Queen's University)
8. Activities in support of the Committee for the Durability of Structures (not funded as separate projects)
   i) Performance of fibre reinforced membranes
   ii) Measurement of cover in reinforced concrete elements
   iii) Durability of concrete culverts
   iv) Policies for achieving durability of structures

The following projects have been discontinued:

9. Development of new aggregate durability (at the University of Windsor)
10. Rehabilitation of decks with active cracks
11. Evaluation of a superplasticizing concrete admixture
12. Corrosion in the Harmer Avenue bridge beams

Research activities in concrete technology within the Research and Development Branch have decreased substantially in recent years from approximately 10 man-years and a total budget of

$ 350,000 in 1978 to approximately 4 man-years and a budget of $150,000 in 1980.

In addition, there are several projects which can be described as applied research, and which are carried out by the Concrete Section of the Engineering Materials Office. These projects fall into two categories: those which require the extensive use of laboratory facilities and those directly in support of site functions.

1. Durability of concrete containing granite and gneiss aggregates (Northern Ontario)
2. Use of granulated blastfurnace slag as a partial replacement for Portland cement
3. Effect of brand of cement on the strength of concrete
4. Sulphate resistance of blended cements
5. Durability of lean concrete bases for pavement construction
6. Adequacy of the air void system in slip-formed concrete barrier walls
7. D-cracking susceptibility of aggregates in concrete pavement in S.W. Ontario
8. Variation of strength in concrete columns

The work done in the Engineering Materials Office involves 4 man-years and about $100,000.

Research on aggregate is undertaken by the Earth and Environment group and there is currently one active project.

At the Ministère des Transports (Québec), activities in concrete come under the Director of Research and Control. As far as concrete is concerned, mainly short-term investigations are undertaken. As for long-term activities, studies are made of deterioration of concrete and of correlation between the behaviour of concrete in structures and laboratory tests on aggregate using conventional tests. It is also proposed to establish a joint programme with the Ecole Polytechnique in Montréal to investigate the alkali-aggregate reaction. The Ministry also adapts foreign techniques and research results to the solution of local problems.

Information on work done in the Department of Transportation of New Brunswick was given by Mr Gerard Keenan, Assistant Highways Director. It appears that no research is done in the Department but there is a fixed concrete laboratory and also mobile laboratories which do routine testing.

Centre de Recherche Industrielle du Québec (CRIQ) is a corporation of the government of Quebec

whose main rôle is to contribute to the economic development of Quebec by promoting innovation in local manufacturing firms. Although the Centre does not do routine testing it does occasionally do so with a view to facilitating work of industry in initial stages and encouraging research within the industry.

In CRIQ, there is a Division of Materials and Industrial Processes which contains, among others, a group dealing with metals and minerals. In this group, and also in the group dealing with organic materials, polymer concrete is developed for external wall panels, for benches in the Montréal Métro and for manholes. Work is also done on development of lightweight polymer concrete, and very recently work has also started on manufacture of expanded clay and shale aggregate using local materials and a suspension kiln; the latter would allow intermittent operation which it is hoped would be economic unlike a rotary kiln which has to be operated continuously. A further small project deals with efflorescence of concrete block.

No work is done on cement or on conventional concrete.

The Research and Productivity Council is a New Brunswick Provincial organisation but it is independent of the Provincial government. In the applied sciences department, whose head is Dr Donovan Abbott, work is done on testing of aggregates and of concrete products and on their quality control. Investigations of failures are also undertaken. None of these can be classified as long-term applied research. The only project falling in that category is the proposed work on utilisation of fly ash which is produced in New Brunswick and which has an extremely high iron content. Even if the work referred to above were classified as applied research, the expenditure on it would not be large.

APPENDIX D

DESCRIPTION OF LONG-TERM APPLIED RESEARCH UNDERTAKEN BY UNIVERSITIES

At the University of British Columbia, work in the field of concrete is done by Dr S. Mindess, Associate Professor of Civil Engineering, who has recently been joined by Mr R. Gray, Assistant Professor of Civil Engineering. Last year's achievements include the development of a large instrumented impact machine for steel fibre concrete. Also, work is starting on studies of aggregate-paste bond with a view to establishing the permeability along the interfacial surface when water is subjected to pressure of several hundred psi. Although this may be classified as fundamental work, its application to marine structures may be considerable. However, so far, no measureable work has been done. The work is done under contract from Martin Marietta in Baltimore but funds originate from the U.S. Navy.

Work actually done in recent years at the University of British Columbia includes cement-wood fibre composites for block and panels and crack

propagation in cement and mortar under stress. The latter project is done in collaboration with Dr Sidney Diamond of Purdue University.

The University of Alberta has a large department of civil engineering. According to Dr J. G. MacGregor, Professor of Civil Engineering, no thesis at the MSc or PhD level has been submitted in the field of cement, aggregate, or concrete, in the last five years. No faculty member has had a major grant from NSERC or from other Federal sources for work in this area. Perhaps it is reasonable to point out that the University of Calgary, also in Alberta, does a great amount of work in the relevant area and it is therefore not surprising that the other university in the Province with a Faculty of Engineering has elected not to be active in direct competition with the University of Calgary.

The University of Calgary is active over a wide range of both material and structural aspects of concrete. Clearly, only some of the work is relevant to the present report, but it may be noted that research grants from NSERC, DRB, CANMET and Canadian Masonry Research Council received during 1980/81 by faculty members of the Department of Civil Engineering totalled $627,000.

Here are some typical examples of the work done.

Dr M. A. Ward, Head of Department of Civil Engineering, is doing work on freeze-thaw properties of mass concrete for Revelstoke Dam in British Columbia. He is also doing work on material characterisation of mass concrete for the Seven-Mile Dam, British Columbia as well as for the Revelstoke Dam. Other projects include durability of spun poles and bridge piers and also the air-void analysis of railway ties. While much of this work is directly related to specific projects, it can be reasonably expected that the advance in knowledge resulting from the work can be generalised and will be useful in future work, and therefore clearly comes under the heading of long-term applied research.

Dr Ward is also doing work in the field of concrete masonry under a research grant in aid from the Canadian Masonry Research Council in Ottawa, which is financed by the Canadian Masonry Contractors' Association. One of the projects involves prediction of the elastic properties of a wall system from properties of constituents: other projects deal with testing of mini-walls and with masonry mortars.

Some of the work on the rôle of microstructure and composition in the durability and strength of building materials is of fundamental nature but will no doubt have applied consequences. The expenditure is $28,000 per annum, but probably only a small fraction should be counted under long-term applied research at this stage.

The same applies to work on stress-temperature-moisture interactions in concrete materials and on fundamental properties of cementitious material. Thus, of the $17,000 spent per annum on these projects, probably very little comes under the applied research heading.

Fundamental work, but with considerable practical application in the short term, is being done on fly ashes in order to determine the properties which make these ashes cementitious and to develop means of making non-cementitious ashes into cementitious ones other than by the addition of Portland cement. The work is done by Dr R. C. Joshi, Professor of Civil Engineering at the University of Calgary under a grant from the Alberta Environment Research Trust. A somewhat related project is production of low-strength concrete from Western fly ash using cement and lime.

The third project on fly ash concerns durability of fly ash concrete exposed to sulphate attack. This project is beginning.

Other projects on fly ash carried out by Dr C. D. Johnston are concerned with freeze-thaw properties of fly ash concrete when extra air entrainment is present and with the use of fly ash to reduce the alkali-aggregate reaction. These projects are supported by NSERC; there are also other grants for these projects and for work on steel-fibre reinforced concrete (material properties and performance in pavement).

As elsewhere in Canada, Dr Johnston is studying the use of superplasticizers; his particular concern is their use in the production of high strength lightweight concrete incorporating fly ash. This work is done under contract from CANMET.

At the University of Saskatchewan, work in the field of concrete is done by Dr K. W. Nasser, Professor of Civil Engineering. One project is concerned with the use of Saskatchewan fly ash in concrete as a partial replacement of different types of cement. Financial support is obtained mainly from NSERC, but there is also a small grant from Saskatchewan Power Corporation. Work is done also on strength and bond qualities of masonry cement under a grant from the

Masonry Association of Saskatchewan.

Over many years, Dr Nasser has been highly successful in development of new techniques and methods for control of concrete with reference to workability, air content, strength, prediction of later strength, and determination of strength in place. This work has resulted in a number of patents and devices.

At the University of Windsor. Dr C. MacInnis, Dean of Engineering and Dr Peter Hudec, Professor of Geological Engineering are the only two faculty members involved in research in concrete and aggregate on a continuing basis. Dr Hudec's work is on aggregates and he has two continuing projects as follows:

a) Development of new aggregate durability specifications for Ontario (supported by the Ministry of Transportation and Communications, Ontario),
b) Development of beneficiation techniques for aggregates (supported by NSERC).

Dr MacInnis has continuing projects in durability, shrinkage and creep of concrete (supported by NSERC).

At the University of Toronto, the situation is as follows. Research on cement, aggregate and concrete is, somewhat surprisingly, done in two sections of the Department of Civil Engineering: the Geotechnical Section and Construction Section. But even so, it is only one faculty member in each section that is involved in the relevant research. In the Geotechnical Section, this is Mr R. H. Mills, Professor of Civil Engineering, who spends, on average, one-quarter of his time on what he describes as "curiosity oriented" research but, as he says, "some of it is also long-term applied research pertaining to the use of blastfurnace slag and fly ash in part substitution for Portland cement." Judging by the titles of papers recently presented, or about to be presented, at meetings by Mr Mills, the various investigations are interesting individual studies rather than a sustained applied research effort of a *coordinated* nature.

In the Construction Section of the Department of Civil Engineering at the University of Toronto, the only research worker in the field of concrete and concrete materials is Dr J. Timusk, Associate Professor of Civil Engineering. In the past, he has done some work on the repair of bridge decks but

now works mainly in the area of dampness and temperature stresses in foundations and basements of houses and small buildings (for the Housing and Urban Development Association of Canada) and in the area of glass-fibre reinforced cement-based polymer-modified materials for non-load bearing purposes such as rain screens and architectural finishes. The latter work is supported by several bodies: National Science and Engineering Research Council, Ontario Ministry of Housing, Housing and Urban Development Association of Canada, and some industrial sources. However, the total support from these bodies (some $10,000) is a surprisingly small sum for Federal, Provincial and industrial sources all together to invest in a development program.

Dr Timusk is also active in the preparation of standards for residential or non-engineering concrete but, of course, this is not a research activity. The activity which can be classified as sustained applied research in the fields covered by the present report is probably very small.

Work in the field of concrete at the University of Toronto is done also in the section of the Department of Civil Engineering which deals with

structural design: Dr S. M. Uzumeri, Professor of Civil Engineering, is about to investigate the possibilities of the use of high-strength concrete in offshore structures. However, no research on high-strength concrete as a material is envisaged and Dr Uzumeri does not see himself as a materials researcher.

At Queen's University, Kingston, Ontario, work is done in the Department of Civil Engineering mainly by Dr B. B. Hope, Professor of Civil Engineering. The topics dealt with are as follows:

a) Autoclaving concrete made with fly ash of American origin. This work is financially supported by CANMET
b) Electrical conductivity of concrete in so far as it is of interest to the study of corrosion of steel in bridge decks. This work is supported by the Ontario Ministry of Transportation and Communications
c) Mix design using aggregates of poor grading. This work is supported by a grant from NSERC
d) Vacuum processing of concrete for the purpose of rehabilitation of bridge decks. This work is supported by the Ontario Ministry of Transportation and Communications

e) Verification of the proposed ISO test method for permeability of concrete with respect to reproducibility. This is work under a CANMET contract

At McGill University in Montreal, no long-term term applied research in the field of cement, aggregate or concrete appears to be pursued, although some such work was done in the past by a faculty member who has since left the university. Teaching in the subject of concrete and concrete materials is carried out by Dr M. S. Mirza, Professor of Civil Engineering.

Work done at the Ecole Polytechnique of the Université de Montréal, was reported by Dr Jules Houde, Associate Professor of Civil Engineering. The main projects are as follows:

a) Early freezing of fresh concrete and prediction of the strength of concrete which had frozen at at an early stage and was subsequently exposed to different types of curing. The work is financed by NSERC

b) Study of aggregates in the Montréal area. This work is done in the Department of Mineral Engineering and is funded by the Québec government. The

purpose of this work is to assess the durability of local aggregates containing shale

c) In future it is proposed to work on creep of concrete with superplasticizers

Dr P.-C. Aïtcin, Professor of Civil Engineering at the Université de Sherbrooke wrote describing his research work related to cement and concrete technology. Half of his time is devoted to concrete research and, at present, he has a research associate and a technician working full time in this field. As well, three undergraduate students have been working on two research projects related to concrete technology. His main fields of interest are:

a) High-strength concrete (>100 MPa)
b) superplasticizers (viscosity measurements, lignosulphonate superplasticizers)
c) lightweight concrete (bubble aggregates)
d) use of industrial by-products in concrete (ilmenite sand, silica dust).

Most of these research projects are sponsored by industrial companies. The dollar value of the research presently in progress at the Université de Sherbrooke he estimates as between $50,000 and $75,000 for the two last years, but he thinks that, for the coming year, the dollar value will be about $100,000.

Information about work done at Université Laval, Quebec, was given to me by Dr Luc Lachance, Associate Professor of Civil Engineering. The main work relevant to the present report is done by Dr Michel Pigeon, Assistant Professor of Civil Engineering who is studying the durability of concrete subjected to long cycles of freezing and thawing and is also working on properties of cold concrete: this work is supported by NSERC.

Information on work done in the Department of Civil Engineering at the University of New Brunswick was given by Mr T. W. Bremner, Professor of Civil Engineering. The main projects are as follows:

a) A general study of the alkali-aggregate reaction with particular reference to local aggregates. This work is done in collaboration with the Department of Geology at the University of New Brunswick
b) Investigation of history of structures which show deterioration due to the alkali-aggregate reaction
c) Strength and deformation of lightweight aggregate concrete with particular reference to the distribution of stresses within the concrete under load
d) Durability of concrete in a marine environment (CANMET contract)

c) Use of fly ash and blastfurnace slag (CANMET contract)

The laboratories in the Department of Civil Engineering are well equipped to carry out a variety of tests on concrete.

The new scanning electron microscope obtained by the University is being used to study the microstructure of low density aggregates. Next year, the microprobe will be used to examine the bonding between cement mortar and masonry units.

The Department has worked over the past six years with the Transportation and Natural Resources Departments of the Province on the topic of alkali-aggregate reactivity and this investigation is to continue with added co-operation from the University Department of Geology.

At the Nova Scotia Technical University, I spoke to Dr J. G. Potyondy, Professor of Civil Engineering. He is no longer active in research on concrete and concrete materials, his last work, not long ago, being an investigation of alkali-aggregate reactivity of specific aggregates done for the Nova Scotia Power Corporation.

APPENDIX E

DESCRIPTION OF LONG-TERM APPLIED RESEARCH UNDERTAKEN BY INDUSTRY

As far as the cement industry in Canada is concerned, there is a very small laboratory connected with the plant laboratory at St Mary's Cement. The largest, and in all likelihood, the only really active laboratory of the cement industry in Canada is the Canada Cement Lafarge Belville Research Laboratory. All the work done is concerned with the production of cement and the following are the main topics:

a) Development of mineralizers in kiln burning for the purpose of dealing with the build-up of chlorides. (The situation is that, using rock with a chloride as low as 0.04 per cent, a build-up of chlorides in the kiln of up to 25 per cent is possible)

b) Investigation of the effect of the size of clinker particles. It is known that larger particles have a higher alkali content and it may be desirable to establish the optimum size of clinker particle from this and other considerations

c) Flowability of cement powder

d) Improvement of efficiency of milling of clinker by way of increasing the capacity of the clinker mill using two air separators in series. This project has a significant energy aspect and some of the research work has been done using funds obtained from the Federal Government and from the Government of Manitoba

e) Work on optimization of energy used by balancing the energy used in grinding the clinker and the energy used in burning the raw meal. Work is also to be done on high sulphur clinkers

f) Canada Cement Lafarge is planning to start work on manufacturing cement with a high magnesia content (5 or even 6 per cent) which could be utilised without causing expansion problems.

It may be noted that Canada Cement Lafarge pays in dues to the Portland Cement Association, Skokie, Illinois, more than $1 million. No work at PCA is done directly to solve specific problems of Canada Cement Lafarge.

According to Mr Stanley Cumming, Manager of Engineering Services of the Canadian Portland Cement Association (or of the Portland Cement Association Canadian Operations), long-term applied research for

the cement industry in Canada forms a part of the work carried out by the Portland Cement Association Research and Development Laboratory, Skokie, Illinois. No work is physically done in Canada.

All Canadian cement producers belong to the Portland Cement Association.

It may be noted that nowadays 90 per cent of the work done in the PCA laboratories at Skokie is contract work, rather than basic or applied research work of a general nature. PCA is collaborating with NRC in the investigation of the behaviour of structural concrete members in fire, but there are no projects specifically directed to materials in or for Canada. However, PCA work on the effect of the length of the freezing cycle, on cold weather concreting and on construction in permafrost is clearly of relevance to Canada.

I also met representatives of the Portland Cement Association in Vancouver, British Columbia and in Halifax, Nova Scotia. They had nothing to add to the report from Ottawa.

Considerable research work in the field of concrete started in June 1979 at Canfarge Ltée.

This company is wholly-owned by Canada Cement Lafarge and provides the back-up and development work for the concrete companies manufacturing block and pipes, also for construction companies and ready-mix companies in all of Canada. The following projects are being pursued:

a) Manufacture of concrete which combines load-bearing capacity with a high insulation value: blocks and panels with a density of 600 to 1000 kg/m^3 and a strength of about 7 MPa are being developed. Such a material has a very high cement factor (500 to 600 kg/m^3), and contains polystyrene in the form of aggregate or sandwich elements. The main practical problems are connected with mixing and workability.

b) Use of superplasticizers in air-entrained concrete to obtain high strengths of the order of 80 MPa with ordinary aggregate. Some of this work is in the nature of basic research on the mechanism of action of superplasticizers.

c) Improvement of durability of concrete by surface coating using a proprietary material, Gelcoat, which is applied to the interior of the mould prior

to placing of concrete. This work is of considerable interest for application to formed vertical surfaces. The work is funded by the Institut du Génie des Matériaux, Montréal, and Canfarge provides the manpower.

d) Introduction of retarded mortar into Canada.

3) In future it is proposed to do work on alkali-aggregate reaction and on glass-fibre reinforced material.

All the above work can be classified as long-term applied research for the purpose of developing new products and is distinct from problem solving.

Information on development work in the field of concrete masonry was given by Dr E. L. Jessop, Director-General, Centre for Research and Development in Masonry which was established in Calgary in 1979. This organisation is mainly doing contract work for the Federal Government and for industry. The chief objective is developing facilities for technical activity in masonry using funds of the Federal Department of Industry, Trade and Commerce. It is

estimated that one-half of the work relates to brick and one-half to concrete masonry. Work is proceeding on the development of a new concrete block of sandwich type.

Hardy Associates (1978) Ltd. is a large firm active, among others, in the field of concrete in a number of locations in Western Canada. Dr D. R. Morgan, Manager, Engineering Materials Division, Burnaby, gave information about the activities of the Burnaby, British Columbia Branch. They are investigating properties of fly ash with a low carbon content but very high calcium carbonate content (up to 30 to 40 per cent). Such fly ash is obtained in the North-Western United States and is imported into British Columbia, as well as in Saskatchewan.

The fly ash can be made hydraulic by the addition of finely divided limestone: strengths of up to 80 per cent of the strength of Portland cement concrete have been obtained, but there are problems in the control of setting and slump loss.

A second problem investigated concerns the use of superplasticizers in concrete with particular reference to the air-void system and lack of durability

even with very low water-cement ratios.

A third project concerns the design of mixes and testing of steel-fibre reinforced shotcrete for use in mines and tunnels. This is development for a specific concrete supplier who markets the material in pre-packed form.

Laboratoire de Béton Limité, Montréal, is a large, well-equipped testing laboratory which provides testing facilities for a great many very large construction projects in Québec. Its President is M. Andre Bisaillon. In connection with one of the construction projects in James Bay, the Laboratoire is conducting research on the durability of concrete in pure and acidic water. This work is done jointly with Hydro-Québec, Societé d'Energie de la Baie James and with CANMET. Hydro-Québec and the Societé supply equipment, local transportation by means of a helicopter and the site manpower, as well as some funds. The initial program on exposure of cylinders and slabs took two years, and now a more intensive program is under way. Results to date indicate that concretes with high water-cement ratios have their surface severely attacked so that it becomes very coarse. Even at low water-cement ratios, etching takes place.

Klohn Leonoff is a firm of consulting engineers active in the field of materials in British Columbia and in Alberta. Dr L. E. Rodway, Head, Materials Engineering Division of the firm in Calgary, gave information about projects undertaken by his company. These are:

a) Accelerated testing of shotcrete and grout using the maturity approach
b) Density determination of fresh and hardened concrete by X-ray emission (application of techniques used for soils) for the purpose of establishing the durability of the surface layer of concrete in place.

Mr P. T. Seabrook of B. H. Levelton and Associates Ltd, Consulting Materials Engineers, gave information on work done in that firm. They employ about 17 people in the field of construction, mainly dealing with concrete. Their research for internal purposes amounts to less than one per cent of annual sales per annum: contract research, including product development, accounts for 15 per cent of annual sales. Investigations for CANMET contracts in the field of fly ash, accelerated curing, and superplasticizers are carried out. Product development is done for private firms, mainly in the areas of admixture

systems, grouts and hardeners, as well as development work on specific projects for special types of concrete such as shotcrete, ultra lightweight concrete for offshore construction, high strength concrete and grouts.

The National Boring and Sounding Inc. in Montreal was a geotechnical company but in recent years it expanded into concrete testing and inspection and does also consultancy for associated engineering companies. National Boring and Sounding is an affiliate of the Lavalin group. According to Dr Gilbert Haddad, Chief of Materials Control, the company is not a research organisation but does routine inspection.

Mr George V. Phillips, Vice-President of Standard Slag Cement Company of Fruitland, Ontario, gave information about work done in his company which is the only manufacturer of blastfurnace slag utilizable in concrete in Canada. In that company, no long-term applied research work is done. Their only activity relevant to the present report is work on sulphate-resistance of concrete made with slag which has been done under contract at McMaster University under the direction of Dr J. Emery.

The object of the research (which is still continuing) was to determine the optimum blend of a high C_3A normal Portland cement with Standard Slag Cement Company's "Cementitious Hydraulic Slag". The optimization is on the basis of good sulphate resistance coupled with structural integrity. This work is supported by grants from the Federal Government and the contribution from Standard Slag is quite small. The company has also developed the use of slag for lean concrete and is planning to expand its work in the future.

The problem arose as to what method of test should be used for this research. Since no agency in North America had taken the Canadian Standards minimum requirements for sulphate resistance and tested them. Therefore, the initial series of tests was to confirm the standard using recommended cement types and blends of high C_3A Portland cements with varying percentage replacements (by mass) of Standard Slag Cement. This is a long range concrete test, which has been under way for four years. Paralleling this work, and to accelerate results, other tests on prisms of standard mortar bars were made.

The last series of accelerated testing was brought about by an engineering query as to the sulphate resistance of these blends when the plastic concrete was placed on a sulphate-bearing soil. Again, no North American testing of this condition had been carried out with the appropriate Portland cement types, and only a report from Germany was available.

Sternson Ltd. of Brantford, Ontario is a small company which, according to its technical director, Mr N. P. Mailvaganam, is doing a considerable amount of long-term applied research, mainly in the area of admixtures. They are experimenting with the use of lignosulphonates as superplasticizers for the purpose of obtaining flowing concrete of not very high strength. Work is also done on the development and properties of expansive additives using lime-based systems, and the calcium sulphoaluminate approach originated in the USSR and currently used in Japan under the name of the Denka system. Other projects are concerned with fibres in expansive mortar and with slag as aggregate.

The work is mostly product development oriented and so that part which can be classified

as long-term applied research is fairly small. Their product line is broad with both cementitious and polymeric materials but the company employs exclusively chemists and a technologist so that it is not able to deal with engineering applications. Sternson Ltd. would be interested in expanding their activity, specifically in the area of blastfurnace slag if financial support, for instance by way of a grant from CANMET, were available. They intend to publish their findings with respect to expansive additives and slump loss in superplasticized concrete.

Work done at Trow Ltd. was described by Mr John A. Bickley, Vice-President of the company. The company does very little research work but it studies deterioration of various horizontal structures, being concerned in surveying the damage they have suffered and in recommending techniques for their repair. Some of this work is supported by NSERC and by the Central Housing and Mortgage Corporation.

Previously, Trow Ltd. did some work under contract for CANMET on the effect on concrete of using crushed sand. This work was done with Mr N. G. Zoldners as consultant. (Mr Zoldners was previously in CANMET.)

Warnock Hersey Professional Services Ltd. in Montréal is a firm concerned with testing and inspection, and the manager of the Construction Materials Department, Dr Rudolph Farsky, oversees testing and inspection as well as investigations in the field of concrete. In addition, a large effort is put into investigations of failures of concrete and of concrete structures. Thus, the firm does very little research, but it does, among others, routine work for Hydro-Québec.

APPENDIX F

MAGAZINE OF CONCRETE RESEARCH 32, No. 110, March 1980

Concrete research news :

from the University of Leeds

Mechanical splicing of reinforcing bars for concrete structures

BACKGROUND

Various mechanical splicing techniques have been, or are being developed as more rapid, efficient and compact alternatives to the conventional lapped splice of reinforcing bars.

OBJECTIVES

(1) To study the performance of a number of types of mechanical splice, in the context of their current development in industry.
(2) To establish suitable test procedures for mechanical splices with a view to eventual standardization.
(3) To make comparative tests of mechanical and lapped splices.

SCOPE OF RESEARCH

The performance of mechanical splices is being investigated by means of (a) tests of spliced bars, and (b) tests of reinforced concrete beams incorporating splices, usually on the tensile reinforcement at the point of maximum moment.

In the tests of spliced bars, extension measurements are made over the various parts of the splice and, where the extension of any part is greater than that of an equivalent length of the parent bar, the effect upon the width of cracks in reinforced concrete is examined. Most of these tests are done under a static tensile load, but a few tests have been made of splices under repeated or alternating load, including a slow cycling alternating load up to 95% of the bar yield stress in both tension and compression.

The tests of reinforced concrete beams are planned to consider the effect of mechanical splices upon both the serviceability and the ultimate limit states of beams with unspliced reinforcement. The programme includes a number of fatigue tests and it is proposed to carry out a series of tests of beams with lapped bar splices, the results of which should be useful as a check of the adequacy of present design requirements.

STAFF

Supervisor: Dr E. W. Bennett
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LEEDS
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Use of sintered domestic refuse as aggregate in concrete

BACKGROUND

The incineration of domestic refuse produces an ash which can be treated to remove both ferrous and non-ferrous metals. The residue can be processed to manufacture an artificial aggregate for use in concrete.

OBJECTIVES

The project described below is examining the behaviour of concrete incorporating this aggregate.

SCOPE OF RESEARCH

A study of the properties of the plastic concrete and the time-dependent properties of the hardened concrete including strength development, durability, elasticity and creep.

Seasonal variations in the composition of the ash and certain parameters of its manufacture are also being examined to see how they might affect the properties of the aggregate.

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Mr P. Robery

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Use of pfa and blastfurnace slags (Cemsave) as partial cement replacements

BACKGROUND

Both materials are essentially industrial by-products and both have cementitious properties when blended with Portland cement. They are known to modify certain properties of the concrete including heat of hydration, sulphate resistance and workability characteristics.

OBJECTIVES

To study the properties of the hardened concrete containing varying proportions of pfa and Cemsave.

SCOPE OF RESEARCH

The work to date has been concerned mainly with Cemsave and its use in large-volume pours to reduce heat of hydration. A study is being made of the short- and long-term properties of concretes stored at normal and elevated temperatures both with and without the addition of Cemsave. It is hoped to begin a similar study using pfa as a replacement.

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Superplasticizers in concrete

BACKGROUND

Developed more than 15 years ago in Japan, this relatively new form of admixture has been in limited use in the UK for about six years. It can be used to transform a concrete of 'medium' workability into a 'flowing' concrete or alternatively to enable a workable concrete to be produced at an extremely low water/cement ratio.

OBJECTIVES

To examine the properties of the hardened concrete produced both at high workabilities and with low water/cement ratios.

SCOPE OF RESEARCH

The time-dependent properties (strength, elasticity, shrinkage, creep, durability) of normal and air-entrained concretes have been studied using the superplasticizer to produce flowing concrete. The properties of concretes using the material as a water-reducing agent to produce high early strengths under both normal and accelerated curing conditions have also been examined.

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Creep of concrete

BACKGROUND

(1) At the moment, accurate prediction of long-term creep and shrinkage for design purposes is a subject of controversy. Long-term data are few in number and these, of course, are essential for ascertaining prediction methods.

(2) Although creep in tension is often ignored, it is important with respect to the onset of cracking in concrete. In addition, its behaviour can be different from creep in compression, a situation which is not explained by creep mechanisms.

(3) Knowledge of creep in uniaxial cyclic compression is required in connection with pavement design, traffic flow over bridges etc., and such knowledge is lacking because cyclic creep cannot be easily estimated from static creep.

OBJECTIVES

(1) To relate 10 year values of creep and shrinkage to their respective short-term values, and to investigate prediction methods.

(2) To compare creep in tension with creep in compression.

(3) To compare creep in cyclic compression with creep under a static load.

SCOPE OF RESEARCH

(1) Eighteen different types of concrete are being used, creep and shrinkage being measured in water

and in air controlled to ambient conditions. Previously established expressions between long-term and short-term (28 days) will be used to determine the accuracy of long-term prediction.

(2) Creep in tension and creep in compression are being compared under conditions of no moisture exchange with the ambient medium (basic creep) and under drying conditions. In addition, the prediction of creep recovery is being investigated.

(3) This project has involved the development of sophisticated strain-measuring equipment to measure strains and hystereses areas. Under cyclic loading, creep increases relative to creep under a static load equal to the main cyclic stress; the causes of this increase are being investigated by corresponding tests, as well as by damping measurements.

STAFF

Supervisors: Dr J. J. Brooks
Dr J. R. Harrop
(in association with
Dr A. M. Neville,
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Research team: Mr P. H. Toseland
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Strength of slender reinforced concrete walls

BACKGROUND

CP110 defines a slender reinforced concrete wall as having a ratio of effective height to thickness greater than 12. If the wall is unbraced, this ratio should not exceed 30. There appear to be few experimental data on this form of construction and, apart from a recent CIRIA Guide on deep beams, little advice exists.

OBJECTIVES

To investigate a range of slender reinforced concrete walls under vertical load and produce design recommendations.

SCOPE OF RESEARCH

The effects upon serviceability and collapse of the following parameters are being examined:

(a) slenderness ratio (height/thickness ratio);
(b) aspect ratio (height/length ratio);
(c) reinforcement (volume and distribution);
(d) bearing area;
(e) wall openings (position and size).

STAFF

Supervisor: Professor A. R. Cusens

Research Assistant: Mr I. I. Besser

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The tensile strength of concrete

BACKGROUND

The measurement of direct tensile strength of concrete is difficult and, in practice, other indirect methods are recommended which give different values. In many cases, it is required to know the tensile strength for different types of loading without resorting to laborious testing.

OBJECTIVE

To relate tensile strength as given by various tests.

SCOPE OF RESEARCH

A theory (highly stressed volume) is being developed to explain tensile strength as measured by the modulus of rupture, indirect splitting and uniaxial tests. Laboratory tests involve a range of mixes, specimen size and storage conditions.

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from The Hatfield Polytechnic

Measurement of microstructure of hardened cement paste (h.c.p.)

BACKGROUND

Much of the work in progress at Hatfield is founded on the belief that a clearer understanding of the microstructure of h.c.p. will lead to the better estimation of, and eventually control of, the major engineering properties of concrete. Virtually all the work described below on material properties is accom-

panied by investigation into the coincidental effects on the microstructure.

Previous research has included the development of methods of determining structure and mineralogy using electron microscopy, X-ray diffraction, mercury intrusion porosimetry, water adsorption and derivative thermogravimetry. A clearer picture of both the solid phases and the pore structure for various water/cement ratios and conditions of storage has resulted.

RESEARCH PROGRAMME

The studies on microstructure are being extended into the finer pores as revealed by nitrogen adsorption in addition to the techniques already established. Current investigations include the effects of temperature change and cement composition, and the influence of various methods of drying.

STAFF

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Herts

Penetration of concrete by potentially deleterious agencies

BACKGROUND

Work on this topic has been in progress for about three years. There are two aspects to the investigation.

Firstly, the permeability to water of both h.c.p. and mortar has been determined under pressure gradients up to 1·5 N/mm² per mm. It has been found that permeability is a multivariate function of total porosity but can be uniquely related to primary continuous pore radius.

Secondly, the penetration of chloride ions into h.c.p. has been studied and it has been found that the concentration of total chloride and bound chloride (in calcium chloroaluminate hydrate) follows a power law with depth of penetration. The ratio of total to bound chloride appears to be constant with depth of penetration, and there are effects on the sizes of the micropores.

RESEARCH PROGRAMME

The work on the penetration of ions is continuing with investigation into the effects of the cations present (sodium, potassium etc.) or the anions present (bromide, iodide etc.). Further work is also in progress on the permeability of mortars.

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Dimensional changes in hardened cement paste (h.c.p.)

BACKGROUND

A fundamental study on the effects of moisture and temperature change in h.c.p. is approaching completion. Various states of water in h.c.p. have been identified and related to the shrinkages and thermal movements observed.

RESEARCH PROGRAMME

The next stage of this investigation has been initiated in which applied stress is being introduced, and immediate strain and creep are being measured. The findings of the earlier programme are being drawn on in planning the concomitant experimentation on the microstructure.

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The effects of shrinkage and creep on restrained lightweight concrete slabs

BACKGROUND

Earlier measurements on structures in service indicated that the occurrence of long-term strains in lightweight concrete flexural members could lead to unexpected structural behaviour.

RESEARCH PROGRAMME

Tests are being performed to measure creep and shrinkage in concrete specimens of varying sizes in order to establish a practical means of estimating

creep and shrinkage in lightweight concrete structural members. Finite element procedures are being developed to represent time-dependent movements and cracking in restrained slabs.

STAFF

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The behaviour under load of reinforced concrete slab–beam systems

BACKGROUND

The project has developed from previous experience of measurements of the behaviour of reinforced concrete slabs and of reinforced concrete beams in torsion.

RESEARCH PROGRAMME

The investigation is directed particularly to the ultimate load behaviour of panel slab–beam systems. It is envisaged that the programme will cover the effects of various ratios of beam/slab stiffnesses and of different support conditions.

STAFF

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Future *Concrete research news*

Further entries for *Concrete research news* are invited by the Editor. They should be modelled on those that have already been published, and should refer either to programmes of research that are just starting or to new phases of programmes that are being embarked upon after a certain amount of preliminary work. The ranges of the variables that it is intended to test (e.g. numbers and sizes of specimens, types of loading, ambient conditions) should be stated, and the names of the supervisor and principal research worker(s) should be given.

There is no closing date for entries. All items accepted will be published in one of the two issues following the date of their receipt by the Editor.

ACKNOWLEDGEMENTS

I am very grateful to all those who generously gave of their time in order to provide me with information on research done in their organisations; their names are listed in Appendix A. I am also most grateful to Mr V. M. Malhotra, Head, Construction Materials Section, CANMET for providing background information and for facilitating contacts with the various agencies.

Dr M. H. Neville contributed significantly in the compilation of this report.

ABOUT THE AUTHOR

Adam Neville, P.Eng., has been Principal and Vice-Chancellor of the University of Dundee, Scotland, since 1978. He holds the degrees of B.Sc. (First Class Honours) in Civil Engineering, M.Sc., Ph.D. and D.Sc. of the University of London and D.Sc. of the University of Leeds; he is a Fellow of the Royal Society of Edinburgh.

Following full-time professional experience, he was Professor of Civil Engineering in Nigeria, and Saskatchewan, and later was Dean of Engineering in the University of Calgary, where he also served as Dean of Graduate Studies. In 1968 he became Head of the Department of Civil Engineering in the University of Leeds, England.

Dr Neville has acted as a consultant to industry and governments in the United Kingdom and abroad. He was among those first elected Fellow of the American Concrete Institute and, in 1973, was the first recipient of the Arthur R. Anderson Award of the American Concrete Institute for outstanding contribution to understanding the behaviour of concrete through research, publications, and teaching. Dr Neville has published extensively, including six books on concrete structures and technology, structural analysis and statistical methods. His principal books have been translated into nine languages and are in use in many countries.

In 1973 Dr Neville prepared for the Department of Industry, Trade and Commerce a report on the feasibility of establishing in Canada an Institute of Concrete Construction.